1. INTRODUCTION AND OVERVIEW OF SOURCES

1.1. BACKGROUND

In May of 1991, the United States Environmental Protection Agency (EPA) announced a scientific reassessment of the human health and exposure issues concerning dioxin and dioxin-like compounds (56 FR 50903). This reassessment resulted in two reports: a health reassessment document (U.S. EPA, 1994a), and an exposure document entitled *Estimating Exposure to Dioxin-Like Compounds*, which expanded upon a 1988 draft exposure report entitled, *Estimating Exposure to 2,3,7,8-TCDD* (U.S. EPA, 1988a). The document *Estimating Exposure to Dioxin-Like Compounds* has now been expanded to four volumes, as discussed below. This document can be used with the health reassessment document to evaluate potential health risks from exposure to dioxin-like compounds.

Numerous public comments were received on the draft documents and they were reviewed by EPA's Science Advisory Board (SAB) in 1995 (U.S. EPA, 1995a). In a related document, EPA also described the data and methods for evaluating risks to aquatic life from 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) (U.S. EPA, 1993a). In 1997, EPA released a workshop review version of Chapter 8 of the Health Reassessment documents, the chapter on dose-response modeling (U.S. EPA, 1997a). In 1998, EPA released a workshop review version of the sources inventory (U.S. EPA, 1998a), one of the four volumes of the current Exposure Reassessment Document. This current version of Volume II, Sources of Dioxin-Like Compounds in the United States, incorporates changes as a result of comments received during numerous scientific and peer review meetings and workshops, including:

- Scientific Peer Review meeting to review and comment on the "Inventory of Sources of Dioxin in the United States", August, 1998

- EPA International Workshop on Formation and Sources of Dioxin-Like Compounds held in Washington, DC in November, 1996. Over 40 technical and scientific experts from academia, industry and public interest groups participated in a 2-day workshop on sources and formation of CDD/CDFs.

- EPA International Workshop on Atmospheric Deposition and Reservoir Sources of Dioxin-like Compounds held in Washington, DC in July, 1996. Over 20 technical and scientific experts from academia participated in a 2-day workshop on characterizing atmospheric deposition and reservoir sources of dioxin-like compounds.

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- Review by EPA's Science Advisory Board (SAB) in 1995.

The purpose of the exposure portion of the dioxin reassessment is threefold: 1) to inventory the known sources of release of dioxins into the environment, 2) to develop an understanding of dioxins in the environment, including fate and transport properties, environmental and exposure media concentrations, background and potentially elevated exposures, and temporal trends in exposure, and 3) provide site-specific procedures for evaluating the incremental exposures due to specific sources of dioxin-like compounds. The exposure document is presented in four volumes. Following is a summary of the material contained in each of these volumes:

Volume I - Executive Summary

This volume includes summaries of findings from Volumes II, III, and IV. It also includes a unique section on research needs and recommendations for dioxin-like compounds.

Volume II - Sources of Dioxin-Like Compounds in the United States

This volume presents the inventory of known sources of dioxin release into the U.S. environment. This inventory is presented for two time frames, represented by the years 1987 and 1995. Ongoing releases into air, water, and soil are quantified where possible. Included within this volume are CDD/CDF congener profiles of source categories.

Volume III - Properties, Environmental Levels, and Background Exposures

This volume presents and evaluates information on the physical-chemical properties, environmental fate, environmental and exposure media levels, background and potentially elevated human exposures, and temporal trends of dioxin-like compounds in the U.S. environment during the 20th century. It summarizes and evaluates relevant information obtained from published literature searches, EPA program offices and other Federal agencies, and published literature. From these data sources, exposure media concentrations, and average as well as potentially elevated exposure levels for the U.S. population are quantified. The data contained in this volume are expected to be current through 1998 with some new information published during 1999.

Volume IV - Site-Specific Assessment Procedures

This volume presents procedures for evaluating the incremental impact from sources of dioxin release into the environment. The sources covered include contaminated soils, stack emissions, and point discharges into surface water. This volume includes sections on: exposure parameters and exposure scenario development; stack emissions and atmospheric transport modeling; aquatic and terrestrial fate, and food chain modeling; demonstration of methodologies; and uncertainty evaluations including exercises on sensitivity analysis and model validation, review of Monte Carlo assessments conducted for dioxin-like compounds, and other discussions. The data contained in this volume are current through 1998 with some new information published during 1999.

1.2. DESCRIPTION OF DIOXIN-LIKE COMPOUNDS

This document addresses compounds in the following chemical classes: polychlorinated dibenzo-p-dioxins (PCDDs or CDDs), polychlorinated dibenzofurans (PCDFs or CDFs), and polychlorinated biphenyls (PCBs). The CDDs include 75 individual compounds, and CDFs include 135 different compounds. These individual compounds are technically referred to as congeners. Only 7 of the 75 congeners of CDDs are thought to have dioxin-like toxicity; these are ones with chlorine substitutions in, at least, the 2, 3, 7, and 8 positions. Only 10 of the 135 possible congeners of CDFs are thought to have dioxin-like toxicity; these also are ones with substitutions in, at least, the 2, 3, 7, and 8 positions. There are 209 PCB congeners. Only 13 of the 209 congeners are thought to have dioxin-like toxicity; these are PCBs with four or more chlorines with just one or no substitution in the ortho position. These compounds are sometimes referred to as coplanar, meaning that they can assume a flat configuration with rings in the same plane. Similarly configured polybrominated biphenyls are likely to have similar properties; however, the data base on these compounds, with regard to dioxin-like activity, has been less extensively evaluated.

The physical/chemical properties of each congener vary according to the degree and position of chlorine substitution. The chlorinated dibenzodioxins and dibenzofurans are tricyclic aromatic compounds with similar physical and chemical properties, and both classes are similar structurally. Certain PCBs (the so-called coplanar or mono-ortho coplanar congeners) are also structurally and conformationally similar. The most widely

studied of these compounds is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). This compound, often called simply dioxin, represents the reference compound for this class of compounds. The structure of 2,3,7,8-TCDD and several related compounds is shown in Figure 1-1.

1.3. TOXICITY EQUIVALENCY FACTORS

The dioxin-like compounds are often found in complex mixtures. For risk assessment purposes, a toxicity equivalency procedure was developed to describe the cumulative toxicity of these mixtures. This procedure involves assigning individual toxicity equivalency factors (TEFs) to the 2,3,7,8 substituted CDD and CDF congeners (the sum of these two is abbreviated as CDD/CDF in this document) and to selected coplanar and mono-ortho PCBs (the sum of the three groups is often abbreviated as CDD/CDF/PCB). TEFs are estimates of the toxicity of dioxin-like compounds relative to the toxicity of 2,3,7,8-TCDD, which is assigned a TEF of 1.0. Calculating the toxic equivalency (TEQ) of a mixture involves multiplying the concentration of individual congeners by their respective TEF. The sum of the TEQ concentrations for the individual congeners is the TEQ concentration for the mixture. This is described mathematically as follows:

$$TEQ \cong \Sigma_{i-n}\left(Congener_i \times TEF_i\right) + \left(Congener_j \times TEF_j\right) + \ldots\ldots\left(Congener_n \times TEF_n\right)$$

TEFs compare the potential toxicity of each dioxin-like compound comprising the mixture to the well-studied and understood toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), originally identified as the most toxic member of the group. To assign TEF values, panels of scientific experts have reviewed the toxicological databases along with considerations of chemical structure, persistence, and resistance to metabolism. A full description of the history and scientific issues associated with the development and use of TEQs can be found in Chapter 9 of Part 2 (Human Health Document). Since 1989, several different TEF schemes have been developed and used for evaluating the TEQ of mixtures of CDDs, CDFs and dioxin-like PCBs. A problem arises in that past and present quantitative exposure and risk assessments may not have clearly identified which of three TEF schemes were used to estimate the TEQ. This Dioxin Exposure Reassessment introduces a new uniform TEQ nomenclature that clearly distinguishes between the different TEF schemes as

well as identifies the congener groups included in specific TEQ calculations. The nomenclature uses the following abbreviations to designate which TEF scheme was used in the TEQ calculation:

- I-TEQ refers to the International TEF scheme adopted by EPA in 1989 (U.S. EPA, 1989). See Table 1-1.
- TEQ-WHO$_{94}$ refers to the 1994 World Health Organization (WHO) extension of the I-TEF scheme to include 13 dioxin-like PCBs (Ahlborg et al., 1994). See Table 1-2.
- TEQ-WHO$_{98}$ refers to the 1998 WHO update to the previously established TEFs for dioxins, furans, and dioxin-like PCBs (Van den Berg et al., 1998). See Table 1-3.

The nomenclature also uses subscripts to indicate which family of compounds are included in any specific TEQ calculation. Under this convention, the subscript D is used to designate dioxins, the subscript F to designate furans and the subscript P to designate PCBs. As an example, "TEQ$_{DF}$-WHO98" would be used to describe a mixture for which only dioxin and furan congeners were determined and where the TEQ was calculated using the WHO$_{98}$ scheme. If PCBs had also been determined, the nomenclature would be "TEQ$_{DFP}$-WHO98."

Note that the designations TEQ$_{DF}$-WHO$_{94}$ and I-TEQ$_{DF}$ are interchangeable as the TEFs for dioxins and furans are the same in each scheme. Note also that in the current draft of this document, I-TEQ sometimes appears without the D and F subscripts. This indicates that the TEQ calculation includes both dioxins and furans. A list of other abbreviations and naming conventions used in this document for dioxin-like compounds is presented in Table 1-4.

1.4. OVERVIEW OF SOURCES AND EMISSIONS INVENTORY METHODOLOGY

In the United States, the major identified sources of environmental release have been grouped into five broad categories for the purposes of this report:

- Combustion Sources: CDD/CDFs are formed in most combustion systems. These can include waste incineration (such as municipal solid waste, sewage sludge, medical waste, and hazardous wastes), burning of various fuels (such as coal, wood, and petroleum products), other high temperature sources (such as cement kilns), and poorly or uncontrolled combustion sources (such as forest fires, building fires, and open burning of wastes).

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- <u>Metals Smelting, Refining and Processing Sources</u>: CDD/CDFs can be formed during various types of primary and secondary metals operations including iron ore sintering, steel production, and scrap metal recovery.

- <u>Chemical Manufacturing</u>: CDD/CDFs can be formed as by-products from the manufacture of chlorine bleached wood pulp, chlorinated phenols (e.g., pentachlorophenol - PCP), PCBs, phenoxy herbicides (e.g., 2,4,5-T), and chlorinated aliphatic compounds (e.g., ethylene dichloride).

- <u>Biological and Photochemical Processes</u>: Recent studies suggest that CDD/CDFs can be formed under certain environmental conditions (e.g., composting) from the action of microorganisms on chlorinated phenolic compounds. Similarly, CDD/CDFs have been reported to be formed during photolysis of highly chlorinated phenols.

- <u>Reservoir Sources</u>: Reservoirs are materials or places that contain previously formed CDD/CDFs or dioxin-like PCBs and have the potential for redistribution and circulation of these compounds into the environment. Potential reservoirs include soils, sediments, biota, water and some anthropogenic materials. Reservoirs become sources when they have releases to the circulating environment.

1.4.1 Overview and Organization of Source Analysis

Only sources judged to have a reasonable likelihood for releases to the "circulating environment" were addressed in ths document. Examples of the circulating environment system boundary are as follows:

- CDD/CDFs and dioxin-like PCBs in air emissions and wastewater discharges were included; whereas, CDD/CDFs and dioxin-like PCBs in intermediate products or internal wastestreams were excluded. For example, the CDD/CDFs in a wastestream going to an on-site incinerator would not be addressed in this document, but any CDD/CDFs in the stack emissions from the incinerator would be included.

- CDD/CDFs and dioxin-like PCBs in wastestreams applied to land in the form of "land farming" are included; whereas, those disposed in permitted landfills were excluded. Properly designed and operated landfills are considered to achieve long-term isolation from the circulating environment. Land farming, however, involves the application of wastes directly to land, clearly allowing for releases to the circulating environment.

The sources addressed in this document (as defined above) can be divided into two subclasses: 1) contemporary formation sources (sources which have essentially simultaneous formation and release) and 2) reservoir sources (materials or places that contain previously formed CDD/CDFs or dioxin-like PCBs that are re-released to

environment). The contemporary formation sources are discussed in Chapters 2 through 11 and the reservoir sources are discussed in Chapter 12. Table 1-5 provides a comprehensive list of all known or suspected sources of CDDs/CDFs in the United States. The checkmarks indicate how each source was classified in terms of the following six categories:

- Contemporary formation sources with reasonably well quantified releases (referred to in this document as the Quantitative Inventory of Sources). These sources are listed in Table 1-5 and release estimates are shown in Tables 1-7 and 1-8.

- Contemporary formation sources with preliminary release estimates. These sources are listed in Table 1-5 and release estimates are shown in Tables 1-11 and 1-12.

- Contemporary formation sources without quantified release estimates. These sources are listed in Table 1-5.

- Reservoir sources with reasonably well quantified releases. These sources are listed in Table 1-5.

- Reservoir sources with preliminary release estimates. These sources are listed in Table 1-5 and release estimates are shown in Tables 1-11 and 1-12.

- Reservoir sources without quantified releases. These sources are listed in Table 1-5.

This document includes discussions on products which contain dioxin-like compounds. Some of these, such as 2,4-D, are considered to be sources since they are clearly used in ways that result in environmental releases. These products have been classified into one of the above six groups. Other products containing dioxin-like compounds, such as bleached chemical wood pulp, do not appear to have environmental releases and are not considered sources. For all CDD/CDF containing products, this document summarizes the available information about the contamination levels and, where possible, makes estimates of the total amount of CDD/CDF produced annually in these products. The information about CDD/CDF levels in products are summarized in Tables 1-13 and 1-14.

1.4.2 Quantitative Inventory of Sources

EPA's Science Advisory Board (SAB) reviewed an earlier draft of the national dioxin source emissions inventory and commented that the effort was comprehensive and

inclusive of most known sources (U.S. EPA, 1995f). However, the SAB emphasized that source emissions are time-dependant, and recommended that emissions be associated with a specific time reference. In consideration of this recommendation, EPA developed in this report emission estimates for two reference years: 1987 and 1995.

EPA selected 1987 primarily because, prior to this time, little empirical data existed for making source specific emission estimates. The first study providing the type of data needed for a national inventory was EPA's National Dioxin Study (U.S. EPA, 1987a). The year 1987 also corresponds roughly with the time when significant advances occurred in emissions measurement techniques and in the development of high resolution mass spectrometry and gas chromatography necessary for analytical laboratories to achieve low level detection of CDD and CDF congeners in environmental samples. Soon after this time, a number of facilities began upgrades specifically intended to reduce CDD/CDF emissions. Consequently, 1987 is also the latest time representative of the emissions occurring before widespread installation of dioxin-specific emission controls.

EPA selected 1995 as the latest time period that could practically be addressed consistent with the time table for producing the rest of the document. The data collected in the companion document to this document on CDD/CDF and dioxin-like PCB levels in environmental media and food were used to characterize conditions in the mid-1990s. So the emissions data and media/food data in these two volumes are presented on a roughly consistent basis. Since 1995, EPA has promulgated regulations limiting CDD/CDF emissions for a number of the source categories that contribute to the inventory including municipal waste combustors, medical waste incinerators, hazardous waste incinerators, cement kilns burning hazardous waste, and pulp and paper facilities using chlorine bleached processes. Consequently, the estimate of releases in the1995 inventory should not be assumed to accurately represent post-1995 releases. EPA intends to periodically revise this inventory.

A key element of the inventory is the method of extrapolation from tested facilities to national estimates of environmental releases. Because not every U.S. facility in each of the source categories have been tested for CDD/CDF emissions and releases, an extrapolation procedure was developed to estimate national emissions for most source categories. Many of the national emission estimates were, therefore, developed using a "top down" approach. The first step in this approach is to derive from the available emission monitoring data an emission factor (or series of emission factors) deemed to be

representative of the source category (or segments of a source category that differ in configuration, fuel type, air pollution control equipment, etc.). The emission factor relates mass of CDD/CDFs or dioxin-like PCBs released into the environment per some measure of activity (e.g., kilograms of material processed per year, vehicle miles traveled per year, etc.). The emission factor is then multiplied by a national value for the activity level basis of the emission factor (e.g., total kilogram [kg] of material processed in the United States annually).

With the exception of certain releases from the bleached chemical wood pulp/paper industry, no source category has estimates developed from a true "bottom up" approach (i.e., estimates developed using site-specific emissions and activity data for all individual sources in a category and then summed to obtain a national total). Existing facility-specific emissions testing and activity level data for some source categories (e.g., municipal solid waste incinerators) supported a semi- "bottom up" approach. In this approach, facility-specific annual emissions were calculated for those facilities with adequate data. For the untested facilities in the class, a subcategory (or class) emission factor was developed by averaging the emission factors for the tested facilities in the class. This average emission factor was then multiplied by the measure of activity for the non-tested facilities in the class. Emissions were summed for the tested facilities and non-tested facilities. In summary, this procedure can be represented by the following equations:

$$E_{total} = \sum E_{tested,i} + \sum E_{untested,i}$$
$$E_{total} = \sum E_{tested,i} + \sum (EF_i * A_i)_{untested}$$

Where: E_{total} = annual emissions from all facilities (g TEQ/yr)

$E_{tested,i}$ = annual emissions from all tested facilities in class I (g TEQ/yr)

$E_{untested,i}$ = annual emissions from all untested facilities class I (g TEQ/yr)

Ef_i = mean emission factor for tested facilities in class I (g TEQ/kg)

A_i = activity measure for untested facilities class I (kg/yr)

Some source categories are made up of facilities that vary widely in terms of design and operating conditions. For these sources, as explained above, an attempt was made to create subcategories that grouped facilities with common features and then to develop

separate emission factors for each subcategory. Implicit in this procedure is the assumption that facilities with similar design and operating conditions should have similar CDD/CDF release potential. For most source categories, however, the specific combination of features that contributes most to CDD/CDF or dioxin-like PCB release is not well understood. Therefore, how to best subcategorize a source category was often problematic. For each subcategorized source category in this report, a discussion is presented about the variability in design and operating conditions, what is known about how these features contribute to CDD/CDF or dioxin-like PCB release, and the rationale for subcategorizing the category.

As discussed above, each source emission calculation required estimates of an "emission factor" and the "activity level." For each emission source, the quantity and quality of the available information for both terms vary considerably. Consequently, it is important that emission estimates be accompanied by some indicator of the uncertainties associated with their development. For this reason, a qualitative confidence rating scheme was developed as an integral part of the emission estimate in consideration of the following factors:

- *Emission Factor* - The uncertainty in the emission factor estimate depends primarily on how well the tested facilities represent the untested facilities. In general, confidence in the emission factor increases with increases in the number of tested facilities relative to the total number of facilities. Variability in terms of physical design and operating conditions within a class or subclass must also be considered. The more variability among facilities, the less confidence that a test of any single facility is representative of that class or subclass. The quality of the supporting documentation also affects uncertainty. Whenever possible, original engineering test reports were used. Peer reviewed reports from the open literature were also used for developing some emission factors. In some cases, however, draft reports that had undergone more limited review were used. In a few cases, unpublished references were used (such as personal communication with experts) and are clearly noted in the text.

- *Activity Level* - The uncertainty in the activity level estimate was judged primarily on the basis of the extent of the underlying data. Estimates derived from comprehensive surveys (including most facilities in a source category) were assigned high confidence. As the number of facilities in the survey relative to the total decreased, confidence also decreased. The quality of the supporting documentation also affects uncertainty. Peer reviewed reports from the open literature (including government and trade association survey data) were considered most reliable. In some cases, however, draft reports that had undergone more limited review were used. In a few cases, unpublished references were used (such as personal communication with experts) and are clearly noted in the text.

The confidence rating scheme, presented in Table 1-6, presents the qualitative criteria used to assign a high, medium, or low confidence rating to the emission factor and activity level terms for those source categories for which emission estimates can be reliably quantified. The overall "confidence rating" assigned to an emission estimate was determined by the confidence ratings assigned to the corresponding "activity level" term and "emission factor" term. If the lowest rating assigned to either the activity level or emission factor terms is "high," then the category rating assigned to the emission estimate is high (also referred to as "A"). If the lowest rating assigned to either the activity level or emission factor terms is "medium," then the category rating assigned to the emission estimate is medium (also referred to as "B"). If the lowest rating assigned to either the activity level or emission factor terms is "low," then the category rating assigned to the emission estimate is low (also referred to as "C"). It is emphasized that this confidence rating scheme should be interpreted as subjective judgements of the relative uncertainty among sources, not statistical measures.

For many source categories, either emission factor information or activity level information were inadequate to support development of reliable quantitative release estimates for one or more media. For some of these source categories, sufficient information was available to make preliminary estimates of emissions of CDD/CDFs or dioxin-like PCBs; however, the confidence in the activity level estimates or emission factor estimates was so low that the estimates cannot be included in the sum of quantified emissions from sources with confidence ratings of A, B and C. These preliminary estimates were given an overall confidence class rating of D (see Tables 1-11 and 1-12). As preliminary estimates of source magnitude, they can be used, however, to help prioritize future research and data collection. The actual magnitude of emissions from these sources could be significantly lower or higher than these preliminary estimates. Although EPA has chosen not to include them in the more thoroughly characterized emissions of the national inventory, Tables 1-11 and 1-12 suggest that some of these poorly characterized sources have the potential of being major contributors of releases to the environment. As the uncertainty around these sources is reduced, they will be included in future inventory calculations. For other sources, some information exists which suggests that they may release dioxin-like compounds; however, the available data were judged to be insufficient for developing any quantitative emission estimate. These source categories were assigned

a confidence category rating of "E" and also were not included in the national inventory (See listings in Table 1-6).

The emission factors developed for the emissions inventory are intended to be used for estimating the total emissions for a source category rather than for individual facilities. EPA has made uncertainty determinations for each of these emission factors based, in part, on the assumption that by applying them to a group of facilities, the potential for overestimating or underestimating individual facilities will to some extent be self compensating. This means that in using these emission factors one can place significantly greater confidence in an emission estimate for a class than can be placed on an emission estimate for any individual facility. Given the limited amount of data available for deriving emission factors, and the limitations of our understanding about facility-specific conditions that determine formation and control of dioxin-like compounds, the current state of knowledge cannot support the development of emission factors that can be used to accurately estimate emissions on an individual facility-specific basis.

1.5. GENERAL FINDINGS OF THE EMISSIONS INVENTORY

Nationwide emission estimates of I-TEQ$_{DF}$ and TEQ$_{DF}$-WHO$_{98}$ for the United States inventory are presented in Tables 1-7 and 1-8, respectively, for those source categories for which emission estimates can be reliably quantified. Nationwide emission estimates for dioxin-like PCBs are presented in Chapter 11. For each source listed in Tables 1-7 and 1-8, estimated emissions are presented only for those media for which data are adequate to enable an estimate to be made. Figures 1-2 and 1-3 are charts that visually display the range of I-TEQ emission estimates to air that are reported in Table 1-7. Figure 1-4 compares the I-TEQ emission estimates to air for the two reference years (i.e., 1987 and 1995).

Table 1-9 lists the I-TEQ$_{DF}$ emission factors used to derive the emission estimates presented in Table 1-7. Table 1-10 lists the TEQ$_{DF}$-WHO$_{98}$ emission factors used to derive the emission estimates presented in Table 1-8. The emission factors used to calculate these emission estimates were derived by setting "not detected" (ND) values in test reports as zeros. Because detection limits were not always reported in test reports, it was not possible to consistently develop emission factors on any other basis (e.g., values set at one-half the detection limit) for all source categories. When detection limits were reported

for all test reports for a given source category, emission factors were calculated and are presented in this report for both ND equals zero and ND equals one-half the detection limit.

Tables 1-11 and 1-12 present preliminary indications of the potential magnitude of I-TEQ$_{DF}$ and TEQ$_{DF}$-WHO$_{98}$ emissions, respectively, from category D sources in reference year 1995. Because of large uncertainties in these estimates, they are not included in the national inventory presented in Tables 1-7 and 1-8. These estimates are based on very limited data whose representativeness is unknown. The estimates were developed primarily as a tool to direct future investigations and studies. The assumed activity levels and emission factors underlying these estimates are also presented in Tables 1-11 and 1-12.

Best estimates of releases of CDD/CDFs to all environmental media (except products) from sources in confidence categories A, B, and C were approximately 2,600 gram (g) I-TEQ$_{DF}$ (2,800 g TEQ$_{DF}$-WHO$_{98}$) in 1995 and 12,400-g I-TEQ$_{DF}$ (13,500 g TEQ$_{DF}$-WHO$_{98}$) in 1987. These estimates were generated by summing the emissions across all sources in the inventory.

The decrease in estimated emissions of dioxin-like compounds between 1987 and 1995 (approximately 80 percent) was due primarily to reductions in emissions from municipal and medical waste incinerators. For both categories, these emission reductions have occurred from a combination of improved combustion and emission controls and from the closing of a number of facilities. Regulations recently promulgated or under development should result in some additional reduction in emissions from major combustion sources.

The environmental releases of CDD/CDFs in the United States occur from a wide variety of sources, but are dominated by releases to the air from combustion sources. The current (i.e., 1995) inventory indicates that quantifiable emissions from combustion sources are more than an order of magnitude greater than quantifiable emissions from all other categories combined. Combustion sources also dominate among category D sources.

Insufficient data are available to comprehensively estimate point source releases of dioxin-like compounds to water. Sound estimates of releases to water are only available for chlorine bleached pulp and paper mills (356 g I-TEQ$_{DF}$ or TEQ$_{DF}$-WHO$_{98}$ for 1987 and 20 g I-TEQ$_{DF}$ or TEQ$_{DF}$-WHO$_{98}$ for 1995) and manufacture of ethylene dichloride/vinyl chloride monomer (< 1 g I-TEQ$_{DF}$ or TEQ$_{DF}$-WHO$_{98}$ in 1995). Other releases to water bodies that

cannot be quantified on the basis of existing data include effluents from POTWs and most industrial/commercial sources.

Based on the available information, the quantitative inventory of sources includes only a limited set of activities that result in direct environmental releases to land. The only releases to land quantified in the national inventory are land application of sewage sludge (103 g I-TEQ$_{DF}$ or 77 g TEQ$_{DF}$-WHO$_{98}$ in 1995) and pulp and paper mill wastewater sludges (1.4 g I-TEQ$_{DF}$ or TEQ$_{DF}$-WHO$_{98}$ in 1995). Not included in the inventory's definition of an environmental release is the disposal of sludge and ashes into approved landfills.

Significant amounts of dioxin-like compounds produced annually are not considered environmental releases and, therefore, are not included in the national inventory. Examples include dioxin-like compounds generated internal to a process, but destroyed before release, waste streams which are disposed of in approved landfills and are therefore outside the definition of annual environmental releases, and products which contain dioxin-like compounds but for which environmental releases, if any, cannot be estimated.

The procedures and results of the U.S. inventory may have underestimated releases from contemporary sources. A number of investigators have suggested that national inventories may underestimate emissions because of the possibility of unknown sources. This claim has been supported with mass balance analyses suggesting that deposition exceeds emissions (Rappe et al., 1991; Harrad et al. 1992b; Bruzy and Hites, 1995). The uncertainty, however, in both the emissions and deposition estimates for the United States prevents the use of this approach for reliably evaluating the issue (U.S. EPA, 1995a). A variety of other arguments, however, indicate that the inventory could underestimate emissions of dioxin-like compounds:

- A number of sources were not included in the inventory even though limited evidence exists indicating that these sources can emit CDD/CDFs. These sources include various components of the metals industries such as electric arc furnaces and foundries and uncontrolled or minimally controlled combustion practices (e.g., backyard trash burning and accidental fires at landfills). Tables 1-11 and 1-12 present preliminary estimates of U.S. national emissions using the emission factors reported in these other studies as though they were representative of emission factors for U.S. facilities.

- The possibility remains that truly unknown sources exist. Many of the sources that are well accepted today were only discovered in the past 10 years. For example, CDD/CDFs were found unexpectedly in the wastewater effluent from bleached pulp and paper mills in the mid 1980s. Ore sintering is now listed as one of the leading

sources of CDD/CDF emissions in Germany, but was not recognized as a source until the early 1990s.

1.6. GENERAL SOURCE OBSERVATIONS

For any given time period, releases from both contemporary formation sources and reservoir sources determine the overall amount of the dioxin-like compounds that are being released to the open and circulating environment. Because existing information is incomplete with regard to quantifying contributions from contemporary and reservoir sources, it is not currently possible to estimate total magnitude of release for dioxin-like compounds into the U.S. environment from all sources. For example, in terms of 1995 releases from reasonably quantifiable sources, this document estimates releases of 2,800 g TEQ_{DF}-WHO_{98} for contemporary formation sources and 2,900 g TEQ_{DF}-WHO_{98} for reservoir sources. In addition, there remains a number of unquantifiable and poorly quantified sources. No quantitative release estimates can be made for agricultural burning or for most CDD/CDF reservoirs or for any dioxin-like PCB reservoirs. The preliminary estimate of 1995 poorly characterized contemporary formation sources is 1,900 g TEQ_{DF}-WHO_{98}.

Current releases of CDD/CDFs to the U.S. environment result principally from anthropogenic activities. This finding applies to both sources of newly formed dioxin-like compounds and reservoir sources. Four lines of evidence support this finding:

- As discussed in Volume III, the companion document to this report, studies of sediment corings in lakes in the United States show a consistent pattern of change in CDD/CDF concentration in the sediments over time. The time period when increases are observed in CDD/CDF levels in sediments coincides with the time period when general industrial activity began increasing rapidly. CDD/CDF concentrations in sediments began to increase around the 1930s, and continued to increase until the 1960s and 1970s. Decreases appear to have occurred only during the most recent time periods (i.e., 1970s and 1980s). These trend observations are consistent among the dated sediment cores collected from over 20 freshwater and marine water bodies in various locations throughout the United States and Europe. Levels of CDD/CDF in sediments from these lakes are considered to be a reasonable indicator of the rate of environmental deposition. The period of increase generally matches the time when a variety of industrial activities began rising and the period of decline appears to correspond with growth in pollution abatement. Some of these pollution abatement actions are likely to have resulted in decreased CDD/CDF emissions (i.e., elimination of much open burning of solid waste, installation of particulate controls on combustors, phase out of leaded gasoline, and bans or restrictions on PCBs, 2,4,5-T, and PCP).

- In at least one case, soil erosion to surface waters, reservoir sources are thought to be a significant contributor to the environment. However, the principal source of CDD/CDFs in surface soils is air deposition. As discussed in the first bullet, it appears that CDD/CDFs associated with air deposition are primarily of anthropogenic origin.

- No large natural sources of CDD/CDF have been identified. EPA's current estimate of emissions from all sources of CDD/CDFs suggests that forest fires are a minor source of emissions compared to anthropogenic combustion activity. Recently CDD/CDFs have been discovered in ball clay deposits in western Mississippi, Kentucky, and Tennessee. Although the origin of the CDD/CDFs in these clays may be natural, it has not been confirmed.

- As discussed in Volume III, the companion document to this report, CDD/CDF levels in human tissues from the general population in industrialized countries are higher than levels observed in less-industrialized countries. Human populations in Europe and North America have significantly higher mean tissue levels (e.g., blood, adipose tissues, and breast milk) than human populations in developing countries of Asia.

Although chlorine is an essential component for the formation of CDD/CDFs in combustion systems, the empirical evidence indicates that for commercial scale incinerators, chlorine levels in feed are not the dominant controlling factor for rates of CDD/CDF stack emissions. Important factors which can affect the rate of CDD/CDF formation include the overall combustion efficiency, post-combustion flue gas temperatures and residence times, and the availability of surface catalytic sites to support CDD/CDF synthesis. Data from bench, pilot and commercial scale combustors indicate that CDD/CDF formation can occur by a number of mechanisms. Some of these data, primarily from laboratory and pilot scale combustors, have shown direct correlation between chlorine content in fuels and rates of CDD/CDF formation. Other data, primarily from commercial scale combustors, show little relation between availability of chlorine in feeds and rates of CDD/CDF formation. These studies are summarized below:

- Evidence from laboratory studies - A number of laboratory studies indicate that changes in the chlorine content of feed materials may result in changes in the amount of CDD/CDFs formed in the post-combustion region of a bench scale combustion system (Kanters and Louw, 1994; Kanters et al., 1996; De Fre and Rymen 1989; Wagner and Green, 1993).

- Evidence from pilot-scale studies - Recent evidence from a pilot-scale combustion study suggests that the amount of CDD/CDFs formed is not strongly correlated with chlorine content of the feed material when the feed material contains less than one percent chlorine; when chlorine in the feed is above one percent, the chlorine feed

content appears to be directly proportional to the amount of CDD/CDFs formed (Wikstrom et al., 1996). Other pilot-scale studies indicate a strong relationship between the amount of HCl formed (from organically-bound chlorine in feeds) and the amount of CDD/CDFs formed (Bruce et al., 1991; Wagner and Green, 1993). Wagner and Green (1993) concluded that a decrease in the levels of organically-bound chlorine in the feed leads to a decrease in chlorinated organic emissions.

- <u>Evidence from studies of full-scale systems</u> - Combustors having poor combustion characteristics and hot-sided particulate control devices show a positive correlation between chlorine in feeds/fuels and CDD/CDF stack emissions (Thomas and Spiro 1995; U.S. EPA, 1987a). Combustors with high combustion efficiency, cool-sided particulate control devices, and advanced dioxin-specific air pollution control systems, however, do not show a strong correlation between chlorine amounts in feeds/fuels and the amount of CDDs/CDFs emitted from the stack (Rigo et al., 1995). This conclusion has been questioned in a paper by Costner (1998) who claims that many of the facilities assessed by Rigo et al. (1996) show a positive (though small) correlation between chlorine in feed and CDD/CDF emissions. Conversely, Costner (1998) also found that about half the facilities showed a weak inverse relationship. The American Society of Mechanical Engineers (ASME) has concluded that, "Whatever effect chlorine has on PCDD/CDF emissions in commercial scale systems is masked by the effect of APCS (air pollution control systems), temperature, ash chemistry, combustion conditions, measurement imprecision, and localized flow stratification (ASME, 1995)."

The conclusion that chlorine in feed is not a strong determinant of CDD/CDF emissions applies to the overall population of commercial scale combustors. For any individual commercial scale combustor, circumstances may exist in which changes in chlorine content of feed could affect CDD/CDF emissions. Based on scientific evidence currently available, reduction in chlorine content of feeds to well-controlled commercial combustors is not likely to result in a significant reduction of CDD/CDF emissions, unless the chlorine content could be brought to near zero. For uncontrolled combustion, such as open burning of household waste, the chlorine content of the waste may play a more significant role in rates of CDD/CDF formation and release than is observed at commercial scale combustors.

Data are available to estimate the amounts of CDD/CDFs contained in only a limited number of commercial products. No systematic survey has been conducted to determine levels of dioxin-like compounds in commercial products. The available data does, however, allow estimates to be made of the amounts of dioxin-like compounds in bleached pulp (24 g I-TEQ$_{DF}$ or TEQ$_{DF}$-WHO$_{98}$ in 1995), POTW sludge used in fertilizers (3.5 g I-TEQ$_{DF}$ or 2.6 g TEQ$_{DF}$-WHO$_{98}$ in 1995), pentachlorophenol-treated wood (8,400 g I-TEQ$_{DF}$ or 4,800 g

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TEQ_{DF}-WHO_{98} in 1995), dioxazine dyes and pigments (< 1 g I-TEQ_{DF} or TEQ_{DF}-WHO_{98} in 1995) and 2,4-D (18.4 g I-TEQ_{DF} or 28.9 g TEQ_{DF}-WHO_{98} in 1995).

No significant release of newly formed dioxin-like PCBs is occurring in the United States. Unlike CDD/CDFs, PCBs were intentionally manufactured in the United States in large quantities from 1929 until production was banned in 1977. Although it has been demonstrated that small quantities of dioxin-like PCBs can be produced during waste combustion, no strong evidence exists that the dioxin-like PCBs are produced in significant quantities as byproducts during combustion or chemical processes. The widespread occurrence of dioxin-like PCBs in the U.S. environment most likely reflects past releases associated with PCB production, use, and disposal. Further support for this finding is based on observations of reductions since the 1980s in PCB concentrations in Great Lakes sediment and other areas.

It is unlikely that the emission rates of CDD/CDFs from known sources correlate proportionally with general population exposures. Although the emissions inventory shows the relative contribution of various sources to total emissions, it cannot be assumed that these sources make the same relative contributions to human exposure. It is quite possible that the major sources affecting CDD/CDF concentrations in food may not be those sources that represent the largest fractions of total emissions in the United States. The geographic locations of sources relative to the areas from which much of the beef, pork, milk, and fish are produced are important to consider. That is, many of the agricultural areas that produce dietary animal fats are not located near or directly down wind of the major sources of dioxin-like compounds.

The contribution of reservoir sources to human exposure may be significant. Several factors support this finding:

- Because the magnitude of releases from current sources of newly formed PCBs are most likely negligible, human exposure to the dioxin-like PCBs is thought to be derived almost completely from reservoir sources. Key pathways involve releases from both soils and sediments to both aquatic and terrestrial food chains. As discussed in Volume III, one third of general population TEQ_{DFP} exposure is due to PCBs. Thus, at least one third of the overall risk from dioxin-like compounds comes from reservoir sources.

- CDD/CDF releases from soil via soil erosion and runoff to waterways may be significant. These releases appear to be greater than releases to water from the primary sources included in the inventory. CDD/CDFs in waterways can bioaccumulate in fish leading to human exposure via consumption of fish. As

discussed in Volume III, fish consumption makes up about one third of the total general population CDD/CDF TEQ exposure. This suggests that a significant portion of the CDD/CDF TEQ exposure could be due to releases from the soil reservoir. It is not known, however, how much of the soil erosion and runoff represents recently deposited CDD/CDFs from primary sources or longer term accumulation. Much of the eroded soil comes from tilled agricultural lands which would include a mix of CDD/CDFs from various deposition times. The age of CDD/CDFs in urban runoff is less clear.

- Potentially, soil reservoirs could have vapor and particulate releases which deposit on plants and enter the terrestrial food chain. The magnitude of this contribution, however, is unknown. EPA plans future studies in agricultural areas which will compare modeled air concentrations from primary sources to measured levels as a way to get further insight to this issue.

1.7.   CONGENER PROFILES OF CDD/CDF SOURCES

This section summarizes congener profiles of known sources of dioxin-like compounds in the United States (Cleverly et. al, 1998). Congener profiles are the fractional distribution of CDD/CDF congeners in an environmental release, in an environmental sample, or in a biological sample. Under some circumstances, these congener profiles may assist researchers in: (1) identification of specific combustion source contributions to near field air measurements of CDD/CDFs; (2) comparing sources in terms of discerning differences in the types and amplitude of CDD/CDF congeners emitted; and (3) providing insights on formation of CDDs and CDFs in various sources and chemicals. There are numerous procedures one could elect to use to derive a congener profile, and there is no single agreed-upon convention (Cleverly et al., 1998; Lorber et al., 1996; Hagenmaier et al., 1994). In this report, congener profiles were developed primarily by calculating the ratio of specific 2,3,7,8-substituted CDDs and CDFs in the emission or product to the total (Cl_4 - Cl_8) CDDs/CDFs. With respect to combustion sources, the profiles were derived by: (a) dividing the congener-specific emission factors by the total (Cl_4 - Cl_8) CDD/CDF emission factor for each tested facility; and (b) then averaging the congener profiles developed for all tested facilities within the combustor type. For chemical processes and commercial chemicals, CDD/CDF profiles were typically generated by dividing average congener concentrations (ppt) in the chemical by the total CDD/CDF present. Profiles for selected source categories are presented in Figure 1-5.

On the basis of inspection and comparisons of the average CDD/CDF congener profiles across combustion and non-combustion sources, the following observations are

made (Cleverly et al., 1998): (These generalizations are derived from this data set, and their application beyond these data is uncertain).

i.   It appears that combustion sources emit all 2,3,7,8-substituted CDDs and CDFs, although in varying percentages of total CDD/CDF.

ii.   In combustion source emissions, 2,3,7,8-TCDD is usually 0.1 to 1.0 percent of total CDD/CDF. The exception to this are stack emissions from industrial oil-fired boilers where the available, but limited data, indicate that 2,3,7,8-TCDD constitutes an average of 7 percent of total CDD/CDF emissions.

iii.   It cannot be concluded that OCDD is the dominant congener for all combustion generated emissions of CDD/CDFs. OCDD dominates total emissions from: mass burn municipal solid waste incinerators (MSWI) that have dry scrubbers and fabric filters (DS/FF) for dioxin controls; industrial oil-fired boilers; industrial wood-fired boilers; unleaded gasoline combustion; diesel fuel combustion in trucks; and sewage sludge incinerators. The dominant congeners for other combustion sources are: 1,2,3,4,6,7,8-HpCDF in emissions from mass burn MSWIs equipped with hot-sided electrostatic precipitators (ESPs); OCDF in emissions from medical waste incineration; 1,2,3,4,6,7,8-HpCDF in hazardous waste incinerators; 2,3,4,7,8-PeCDF in cement kilns burning hazardous waste; 2,3,7,8-TCDF in cement kilns not burning hazardous waste; OCDF in industrial/utility coal-fired boilers; 1,2,3,4,6,7,8-HpCDF in secondary aluminum smelters; and 2,3,7,8-TCDF in secondary lead smelters.

iv.   The 1,2,3,4,6,7,8-HpCDF appears to be the dominant congener in the following sources: secondary aluminum smelters; MSWIs equipped with hot-sided ESPs; hazardous waste incinerators; and 2,4-D salts and esters.

v.   Evidence for a shift in the congener patterns potentially caused by the application of different air pollution control systems within a combustion source-type can be seen in the case of mass burn MSWIs. For mass burn MSWIs equipped with hot-sided ESPs, the most prevalent CDD/CDF congeners are: 1,2,3,4,6,7,8-HpCDF; OCDD; 1,2,3,4,6,7,8-HpCDD/1,2,3,4,7,8-HxCDF; 2,3,4,6,7,8-HxCDF/OCDF; 1,2,3,6,7,8-HxCDF. The most prevalent congeners emitted from MSWIs equipped with DS/FF are: OCDD; 1,2,3,4,6,7,8-HpCDD; 1,2,3,4,6,7,8-HpCDF; OCDF; 2,3,7,8-TCDF/1,2,3,4,7,8-HxCDD; 2,3,4,6,7,8-HxCDF.

vi.   There is evidence of marked differences in the distribution of CDD/CDF congeners between cement kilns burning and not burning hazardous waste. When not burning hazardous waste as supplemental fuel, the dominant congeners appear to be 2,3,7,8-TCDF; OCDD; 1,2,3,4,6,7,8-HpCDD, and OCDF. When burning hazardous waste, the dominant congeners are: 2,3,7,8-PeCDF; 2,3,7,8-TCDF; 1,2,3,4,7,8-HxCDF; and 1,2,3,4,6,7,8-HpCDD. When burning hazardous waste, OCDD and OCDF are minor constituents of stack emissions.

vii.   The congener profile of 2,4-D salts and esters seems to mimic a combustion source profile in the number of congeners represented, and in the minimal amount of 2,3,7,8-TCDD relative to all 2,3,7,8-substituted congeners. A major difference is

the prevalence of 1,2,3,7,8-PeCDD in 2,4-D (i.e., 14 percent), which is not seen in any other combustion or non-combustion sources presented here.

viii.   There are similarities in the congener profiles of pentachlorophenol (PCP), diesel truck emissions, unleaded gasoline vehicle emissions, and industrial wood combustors. In these sources, OCDD dominates total emissions, but the relative ratio of 1,2,3,4,6,7,8-HpCDD to OCDD is also quite similar.

ix.   The congener profiles for diesel truck exhaust and air measurements from a tunnel study of diesel traffic are quite similar.

Table 1-1. The TEF Scheme for I-TEQ$_{DF}$

Dioxin (D) Congener	TEF	Furan (F) Congener	TEF
2,3,7,8-TCDD	1.0	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	0.5	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
OCDD	0.001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	

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Table 1-2. The TEF Scheme for Dioxin-Like PCBs, as Determined
by the World Health Organization in 1994

Chemical Structure	IUPAC Number	TEF
3,3',4,4'-TeCB	PCB-77	0.0005
2,3,3',4,4'-PeCB	PCB-105	0.0001
2,3,4,4',5-PeCB	PCB-114	0.0005
2,3',4,4',5-PeCB	PCB-118	0.0001
2',3,4,4',5-PeCB	PCB-123	0.0001
3,3',4,4',5-PeCB	PCB-126	0.1
2,3,3',4,4',5-HxCB	PCB-156	0.0005
2,3,3',4,4',5'-HxCB	PCB-157	0.0005
2,3',4,4',5,5'-HxCB	PCB-167	0.00001
3,3',4,4',5,5'-HxCB	PCB-169	0.01
2,2',3,3',4,4',5-HpCB	PCB-170	0.0001
2,2',3,4,4',5,5'-HpCB	PCB-180	0.00001
2,3,3',4,4',5,5'-HpCB	PCB-189	0.0001

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Table 1-3. The TEF Scheme for TEQ_{DFP}-WHO_{98}

Dioxin Congeners	TEF	Furan Congeners	TEF
2,3,7,8-TCDD	1.0	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	1.0	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
OCDD	0.0001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	0.0001

Chemical Structure	IUPAC Number	TEF
3,3',4,4'-TeCB	PCB-77	0.0001
3,4,4',5-TCB	PCB-81	0.0001
2,3,3',4,4'-PeCB	PCB-105	0.0001
2,3,4,4',5-PeCB	PCB-114	0.0005
2,3',4,4',5-PeCB	PCB-118	0.0001
2',3,4,4',5-PeCB	PCB-123	0.0001
3,3',4,4',5-PeCB	PCB-126	0.1
2,3,3',4,4',5-HxCB	PCB-156	0.0005
2,3,3',4,4',5'-HxCB	PCB-157	0.0005
2,3',4,4',5,5'-HxCB	PCB-167	0.00001
3,3',4,4',5,5'-HxCB	PCB-169	0.01
2,3,3',4,4',5,5'-HpCB	PCB-189	0.0001

Table 1-4. Nomenclature for Dioxin-Like Compounds

Term/Symbol	Definition
Congener	Any one particular member of the same chemical family (e.g., there are 75 congeners of chlorinated dibenzo-p-dioxins).
Congener Group	Group of structurally related chemicals that have the same degree of chlorination (e.g., there are eight congener groups of CDDs, monochlorinated through octochlorinated).
Isomer	Substances that belong to the same congener group (e.g., 22 isomers constitute the congener group of TCDDs).
Specific Isomer	Denoted by unique chemical notation (e.g., 2,4,8,9-tetrachlorodibenzofuran is referred to as 2,4,8,9-TCDF).
D	Symbol for congener class: dibenzo-p-dioxin
F	Symbol for congener class: dibenzofuran
M	Symbol for mono (i.e., one halogen substitution)
D	Symbol for di (i.e., two halogen substitution)
Tr	Symbol for tri (i.e., three halogen substitution)
T	Symbol for tetra (i.e., four halogen substitution)
Pe	Symbol for penta (i.e., five halogen substitution)
Hx	Symbol for hexa (i.e., six halogen substitution)
Hp	Symbol for hepta (i.e., seven halogen substitution)
O	Symbol for octa (i.e., eight halogen substitution)
CDD	Chlorinated dibenzo-p-dioxins, halogens substituted in any position
CDF	Chlorinated dibenzofurans, halogens substituted in any position
PCB	Polychlorinated biphenyls
2378	Halogen substitutions in the 2,3,7,8 positions

Source: Adapted from U.S. EPA (1989)

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Table 1-5. List of Known and Suspected CDD/CDF-Sources

Emission Source Category	Contemporary Formation Sources			Reservoir Sources		
	Quantifiable	Preliminary Estimate	Not Quantifiable	Quantifiable	Preliminary Estimate	Not Quantifiable
I. COMBUSTION SOURCES *Waste Incineration* Municipal waste incineration	✓					
Hazardous waste incineration	✓					
Boilers/industrial furnaces	✓					
Medical waste/pathological incineration	✓					
Crematoria	✓					
Sewage sludge incineration	✓					
Tire combustion	✓					
Pulp and paper mill sludge incinerators	✓					
BioGas combustion		✓				
Power/Energy Generation Vehicle fuel combustion - leaded[b]	✓					
- unleaded	✓					
- diesel	✓					
Wood combustion - residential	✓					
- industrial	✓					
Coal combustion - residential		✓				
- industrial/utility	✓					
Oil combustion - residential		✓				
- industrial/utility	✓					
Other High Temperature Sources Cement kilns (haz waste burning)	✓					
Cement kilns (non haz waste burning)	✓					
Asphalt mixing plants		✓				
Petro. refining catalyst regeneration	✓					
Cigarette combustion	✓					
Carbon reactivation furnaces	✓					
Kraft recovery boilers	✓					

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Table 1-5. List of Known and Suspected CDD/CDF-Sources (continued)

Emission Source Category	Contemporary Formation Sources			Reservoir Sources		
	Quantifiable	Preliminary Estimate	Not Quantifiable	Quantifiable	Preliminary Estimate	Not Quantifiable
Minimally Controlled or Uncontrolled Combustion Combustion of landfill gas in flares		✓				
Landfill fires		✓				
Accidental fires (structural)		✓				
Accidental fires (vehicles)		✓				
Forest, brush, and straw fires[d]	✓					
Backyard barrel burning		✓				
Uncontrolled combustion of PCBs			✓			
II. METAL SMELTING/REFINING *Ferrous metal smelting/refining*						
- Sintering plants	✓					
- Coke production		✓				
- Electric arc furnaces		✓				
- Ferrous foundries		✓				
Nonferrous metal smelting/refining						
- Primary aluminum			✓			
- Primary copper	✓					
- Primary magnesium			✓			
- Primary nickel			✓			
- Secondary aluminum	✓					
- Secondary copper	✓					
- Secondary lead	✓					
Scrap electric wire recovery	✓					
Drum and barrel reclamation	✓					
III. CHEMICAL MANUFACTURING (*Releases to the Environment*) Bleached chemical wood pulp and paper mills	✓					
Mono- to tetrachlorophenols			✓			
Pentachlorophenol			✓			
Chlorobenzenes			✓			
Chlorobiphenyls (leaks/spills)			✓			

Table 1-5. List of Known and Suspected CDD/CDF-Sources (continued)

Emission Source Category	Contemporary Formation Sources			Reservoir Sources		
	Quantifiable	Preliminary Estimate	Not Quantifiable	Quantifiable	Preliminary Estimate	Not Quantifiable
Ethylene dichloride/vinyl chloride	✓					
Dioxazine dyes and pigments			✓			
2,4-Dichlorophenoxy acetic acid			✓			
Municipal wastewater treatment		✓				
Tall oil-based liquid soaps			✓			
IV. BIOLOGICAL AND PHOTOCHEMICAL PROCESSES			✓			
V. RESERVOIR SOURCES *Natural*						
- Land					✓	
- Air						✓
- Water						✓
- Sediments						✓
Anthropogenic Structures						
- PCP Treated Wood						✓

Table 1-6. Confidence Rating Scheme for U.S. Emission Estimates

Confidence Rating	Activity Level Estimate	Emission Factor Estimate
Categories/Media for Which Releases Can Be Reasonably Quantified		
High	Derived from comprehensive survey	Derived from comprehensive survey
Medium	Based on estimates of average plant activity level and number of plants or limited survey	Derived from testing at a limited but reasonable number of facilities believed to be representative of source category
Low	Based on data judged possibly nonrepresentative	Derived from testing at only a few, possibly nonrepresentative facilities or from similar source categories
Categories/Media for Which Releases Cannot Be Reasonably Quantified		
Preliminary Estimate	Based on extremely limited data, judged to be clearly nonrepresentative	Based on extremely limited data, judged to be clearly nonrepresentative
Not Quantified	No data available	1) Argument based on theory but no data, or 2) Data available indicating formation, but not in a form that allows developing an emission factor

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Table 1-7. Quantitative Inventory of Environmental Releases of
I-TEQ$_{DF}$ in the United States

Emission Source Category	Confidence Rating[a] Reference Year1995			Confidence Rating[a] Reference Year 1987		
	A	B	C	A	B	C
Releases (g TEQ/yr) to Air						
Waste Incineration Municipal waste incineration		1,100			7,915	
Hazardous waste incineration		5.7			5.0	
Boilers/industrial furnaces			0.38			0.77
Medical waste/pathological incineration			461			2,440
Crematoria			9.1			5.5
Sewage sludge incineration		14.6			6.0	
Tire combustion			0.11			0.11
Pulp and paper mill sludge incinerators[e]						
Power/Energy Generation Vehicle fuel combustion - leaded[b]			1.7			31.9
- unleaded			5.6			3.3
- diesel			33.5			26.3
Wood combustion - residential			62.8			89.6
- industrial		26.2			25.1	
Coal combustion - utility		60.9			51.4	
Oil combustion - industrial/utility			9.3			15.5
Other High Temperature Sources Cement kilns (hazardous waste burning)			145.3			109.6
Lightweight aggregate kilns burning hazardous waste			3.3			2.4
Cement kilns (non hazardous waste burning)			16.6			12.7
Petroleum refining catalyst regeneration			2.11			2.14
Cigarette combustion			0.8			1.0
Carbon reactivation furnaces			0.08			0.06
Kraft recovery boilers		2.3			2.0	
Minimally Controlled or Uncontrolled Combustion Forest, brush, and straw fires[d]			208			170
Metallurgical Processes Ferrous metal smelting/refining						
- Sintering plants		25.1				29.3
Nonferrous metal smelting/refining						
- Primary copper		< 0.5			< 0.5	
- Secondary aluminum			27.4			15.3
- Secondary copper			266			966
- Secondary lead		1.63			1.22	
Drum and barrel reclamation			0.08			0.08
Chemical Manufac./Processing Sources Ethylene dichloride/vinyl chloride		11.2				
TOTAL QUANTIFIED RELEASES TO AIR[c] (g/yr)		2,501			11,928	

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Table 1-7. Quantitative Inventory of Environmental Releases of
I-TEQ$_{DF}$ in the United States (continued)

Emission Source Category	Confidence Rating[a] Reference Year1995			Confidence Rating[a] Reference Year 1987		
	A	B	C	A	B	C
Releases (g TEQ/yr) to Water						
Chemical Manuf./Processing Sources Bleached chemical wood pulp and paper mills	19.5			356		
Ethylene dichloride/vinyl chloride		0.43				
TOTAL QUANTIFIED RELEASES TO WATER[c]		19.93			356	
Releases (g TEQ/yr) to Land						
Chemical Manuf./Processing Sources Bleached chemical wood pulp and paper mill sludge	1.4			14.1		
Ethlyene dichloride/vinyl chloride		0.73				
Municipal wastewater treatment sludge	103			103		
Commercially marketed sewage sludge	3.5			3.5		
2,4-Dichlorophenoxy acetic acid	18.4			21.3		
TOTAL QUANTIFIED RELEASES TO LAND[c]		127.03			141.8	
OVERALL QUANTIFIED RELEASES TO THE OPEN and CIRCULATING ENVIRONMENT		2,648			12,426	

[a] A = Characterization of the Source Category judged to be **Adequate for Quantitative Estimation** with **High Confidence** in the **Emission Factor** and **High Confidence** in **Activity Level**.
   B = Characterization of the Source Category judged to be **Adequate for Quantitative Estimation** with **Medium Confidence** in the **Emission Factor** and at least **Medium Confidence** in **Activity Level**.
   C = Characterization of the Source Category judged to be **Adequate for Quantitative Estimation** with **Low Confidence** in either the **Emission Factor** and/or the **Activity Level**.
[b] Leaded fuel production and the manufacture of motor vehicle engines requiring leaded fuel for highway use have been prohibited in the United States. (See Section 4.1 for details.)
[c] TOTAL reflects only the total of the estimates made in this report.
[d] It is not known what fraction, if any, of the estimated emissions from forest fires represents a "reservoir" source. The estimated emissions may be solely the result of combustion.
[e] Included within estimate for Wood Combustion - industrial.

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Table 1-8. Quantitative Inventory of Environmental Releases of TEQ_{DF}-WHO_{98} in the United States

Emission Source Category	Confidence Rating[a] Reference Year 1995			Confidence Rating[a] Reference Year 1987		
	A	B	C	A	B	C
Releases (g TEQ/yr) to Air						
Waste Incineration Municipal waste incineration		1,250			8,877	
Hazardous waste incineration		5.8			5.0	
Boilers/industrial furnaces			0.39			0.78
Medical waste/pathological incineration			488			2,590
Crematoria			9.1[e]			5.5[e]
Sewage sludge incineration		14.8			6.1	
Tire combustion			0.11			0.11
Pulp and paper mill sludge incinerators[f]						
Power/Energy Generation Vehicle fuel combustion - leaded[b]			2.0			37.5
- unleaded			5.9			3.6
- diesel			35.5			27.8
Wood combustion - residential			62.8[e]			89.6[e]
- industrial		27.6			26.4	
Coal combustion - utility		60.1			50.8	
Oil combustion - industrial/utility			10.7			17.8
Other High Temperature Sources Cement kilns (hazardous waste burning)			156.1			117.8
Lightweight aggregate kilns burning hazardous waste			3.3[e]			2.4[e]
Cement kilns (non hazardous waste burning)			17.8			13.7
Petroleum Refining Catalyst Regeneration			2.21			2.24
Cigarette combustion			0.8			1.0
Carbon reactivation furnaces			0.08[e]			0.06[e]
Kraft recovery boilers		2.3			2.0	
Minimally Controlled or Uncontrolled Combustion Forest, brush, and straw fires[d]			208[e]			170[e]
Metallurgical Processes Ferrous metal smelting/refining						
- Sintering plants		28.0				32.7
Nonferrous metal smelting/refining						
- Primary copper		< 0.5[e]			< 0.5[e]	
- Secondary aluminum			29.1			16.3
- Secondary copper			271			983
- Secondary lead		1.72			1.29	
Drum and barrel reclamation			0.08			0.08
Chemical Manufac./Processing Sources Ethylene dichloride/vinyl chloride		11.2[e]				
TOTAL QUANTIFIED RELEASES TO AIR[c]		2,705			13,081	

Table 1-8. Quantitative Inventory of Environmental Releases of
TEQ_{DF}-WHO_{98} in the United States (continued)

Emission Source Category	Confidence Rating[a] Reference Year 1995			Confidence Rating[a] Reference Year 1987		
	A	B	C	A	B	C
Releases (g TEQ/yr) to Water						
Chemical Manuf./Processing Sources Bleached chemical wood pulp and paper mills	19.5			356		
Ethylene dichloride/vinyl chloride		0.43[e]				
TOTAL QUANTIFIED RELEASES TO WATER[c]	19.93			356		
Releases (g TEQ/yr) to Land						
Chemical Manuf./Processing Sources Bleached chemical wood pulp and paper mill sludge	1.4			14.1		
Ethlyene dichloride/vinyl chloride		0.73[e]				
Municipal wastewater treatment sludge	76.6			76.6		
Commercially marketed sewage sludge	2.6			2.6		
2,4-Dichlorophenoxy acetic acid	28.9			33.4		
TOTAL QUANTIFIED RELEASES TO LAND[c]	110.23			126.7		
OVERALL QUANTIFIED RELEASES TO THE OPEN and CIRCULATING ENVIRONMENT	2,835			13,564		

[a] A = Characterization of the Source Category judged to be **Adequate for Quantitative Estimation** with **High Confidence** in the **Emission Factor** and **High Confidence** in **Activity Level**.
B = Characterization of the Source Category judged to be **Adequate for Quantitative Estimation** with **Medium Confidence** in the **Emission Factor** and at least **Medium Confidence** in **Activity Level**.
C = Characterization of the Source Category judged to be **Adequate for Quantitative Estimation** with **Low Confidence** in either the **Emission Factor** and/or the **Activity Level**.

[b] Leaded fuel production and the manufacture of motor vehicle engines requiring leaded fuel for highway use have been prohibited in the United States. (See Section 4.1 for details.)

[c] TOTAL reflects only the total of the estimates made in this report.

[d] It is not known what fraction, if any, of the estimated emissions from forest fires represents a "reservoir" source. The estimated emissions may be solely the result of combustion.

[e] Congener-specific emissions data were not available; the I-TEQ_{DF} emission estimate was used as a surrogate for the TEQ_{DF}-WHO_{98} emission estimate.

[f] Included within estimate for Wood Combustion - Industrial.

Table 1-9. I-TEQ$_{DF}$ Emission Factors Used to Develop National
Emission Inventory Estimates of Releases to Air

Emission Source	I-TEQ$_{DF}$ Emission Factor		Emission Factor Units
	1995	1987	
Waste Incineration Municipal waste incineration	38.2[a]	573[a]	ng TEQ/kg waste combusted
Hazardous waste incineration	3.83	3.83	ng TEQ/kg waste combusted
Boilers/industrial furnaces	0.64	0.64	ng TEQ/kg waste combusted
Medical waste/pathological incineration	598[a]	1,706[a]	ng TEQ/kg waste combusted
Crematoria	17	17	μg TEQ/body
Sewage sludge incineration	6.94	6.94	ng TEQ/kg dry sludge combusted
Tire combustion	0.282	0.282	ng TEQ/kg tires combusted
Pulp and paper mill sludge incinerators	b	b	
Power/Energy Generation Vehicle fuel combustion - leaded[b]	45	45	pg TEQ/km driven
- unleaded	1.5	1.5	pg TEQ/km driven
- diesel	172	172	pg TEQ/km driven
Wood combustion - residential	2	2	ng TEQ/kg wood combusted
- industrial	0.56 to 13.2[c]	0.56 to 13.2[c]	ng TEQ/kg wood combusted
Coal combustion - utility	0.079	0.079	ng TEQ/kg coal combusted
Oil combustion - industrial/utility	0.20	0.20	ng TEQ/L oil combusted
Other High Temperature Sources Cement kilns burning hazardous waste	1.04 to 28.58[e]	1.04 to 28.58[e]	ng TEQ/kg clinker produced
Cement kilns not burning hazardous waste	0.27	0.27	ng TEQ/kg clinker produced
Petroleum refining catalyst regeneration	1.52	1.52	ng TEQ/barrel reformer feed
Cigarette combustion	0.00043 to 0.0029	0.00043 to 0.0029	ng TEQ/cigarette
Carbon reactivation furnaces	1.2	1.2	ng TEQ/kg of reactivated carbon
Kraft recovery boilers	0.029	0.029	ng TEQ/kg solids combusted
Minimally Controlled or Uncontrolled Combustion Forest, brush, and straw fires	2	2	ng TEQ/kg biomass combusted
Metallurgical Processes Ferrous metal smelting/refining			
- Sintering plants	0.55 to 4.14	0.55 to 4.14	ng TEQ/kg sinter
Nonferrous metal smelting/refining			
- Primary copper	< 0.31	< 0.31	ng TEQ/kg copper produced
- Secondary aluminum smelting	21.1	21.1	ng TEQ/kg scrap feed
- Secondary copper smelting	d	d	ng TEQ/kg scrap consumed
- Secondary lead smelters	0.05 to 8.31	0.05 to 8.31	ng TEQ/kg lead produced
Drum and barrel reclamation	16.5	16.5	ng TEQ/drum
Chemical Manuf./Processing Sources Ethylene dichloride/vinyl chloride	0.95[a]		ng TEQ/kg EDC produced

a Different emission factors were derived for various subcategories within this industry; the value listed is a weighted average.

b Included within total for Wood Combustion - Industrial.

c Emission factor of 0.56 ng I-TEQ$_{DF}$/kg used for non-salt-laden wood; emission factor of 13.2 ng I-TEQ$_{DF}$/kg used for salt-laden wood.

d Facility-specific emission factors were used ranging from 3.6 to 16,600 ng I-TEQ$_{DF}$/kg scrap consumed.

e Emission factor of 1.04 ng I-TEQ$_{DF}$/kg used for kilns with APCD inlet temperatures less than 450°F; emission factor of 28.58 ng I-TEQ$_{DF}$/kg used for kilns with APCD inlet temperatures greater than 450°F.

TEQ = Toxic equivalency factor.

ng = nanogram.

kg = kilogram.

pg = picogram.

Table 1-10. TEQ$_{DF}$-WHO$_{98}$ Emission Factors Used to Develop National
Emission Inventory Estimates of Releases to Air

Emission Source	TEQ$_{DF}$-WHO$_{98}$ Emission Factor		Emission Factor Units
	1995	1987	
Waste Incineration Municipal waste incineration	43.4[a]	644[a]	ng TEQ/kg waste combusted
Hazardous waste incineration	3.88	3.88	ng TEQ/kg waste combusted
Boilers/industrial furnaces	0.65	0.65	ng TEQ/kg waste combusted
Medical waste/pathological incineration	633[a]	1,811[a]	ng TEQ/kg waste combusted
Crematoria	17[f]	17[f]	μg TEQ/body
Sewage sludge incineration	7.04	7.04	ng TEQ/kg dry sludge combusted
Tire combustion	0.281	0.281	ng TEQ/kg tires combusted
Pulp and paper mill sludge incinerators	b	b	
Power/Energy Generation Vehicle fuel combustion - leaded[b]	53	53	pg TEQ/km driven
- unleaded	1.6	1.6	pg TEQ/km driven
- diesel	182	182	pg TEQ/km driven
Wood combustion - residential	2[f]	2[f]	ng TEQ/kg wood combusted
- industrial	0.60 to 13.2	0.60 to 13.2	ng TEQ/kg wood combusted
Coal combustion - utility	0.078	0.078	ng TEQ/kg coal combusted
Oil combustion - industrial/utility	0.23	0.23	ng TEQ/L oil combusted
Other High Temperature Sources Cement kilns burning hazardous waste	1.11 to 30.70[e]	1.11 to 30.70[e]	ng TEQ/kg clinker produced
Cement kilns not burning hazardous waste	0.29	0.29	ng TEQ/kg clinker produced
Petroleum refining catalyst regeneration	1.59	1.59	ng TEQ/barrel reformer feed
Cigarette combustion	0.00044 to 0.0030	0.00044 to 0.0030	ng TEQ/cigarette
Carbon reactivation furnaces	1.2[f]	1.2[f]	ng TEQ/kg of reactivated carbon
Kraft recovery boilers	0.028	0.028	ng TEQ/kg solids combusted
Minimally Controlled or Uncontrolled Combustion Forest, brush, and straw fires	2[f]	2[f]	ng TEQ/kg biomass combusted
Metallurgical Processes Ferrous metal smelting/refining			
- Sintering plants	0.62 to 4.61	0.62 to 4.61	ng TEQ/kg sinter
Nonferrous metal smelting/refining			
- Primary copper	< 0.31[f]	< 0.31[f]	ng TEQ/kg copper produced
- Secondary aluminum smelting	22.4	22.4	ng TEQ/kg scrap feed
- Secondary copper smelting	d	d	ng TEQ/kg scrap consumed
- Secondary lead smelters	0.05 to 8.81	0.05 to 8.81	ng TEQ/kg lead produced
Drum and barrel reclamation	17.5	17.5	ng TEQ/drum
Chemical Manuf./Processing Sources Ethylene dichloride/vinyl chloride	0.95[a,f]		ng TEQ/kg EDC produced

a Different emission factors were derived for various subcategories within this industry; the value listed is a weighted average.
b Included within total for Wood Combustion - Industrial.
c Emission factor of 0.60 ng TEQ$_{DF}$-WHO$_{98}$/kg used for non-salt-laden wood; emission factor of 13.2 ng I-TEQ$_{DF}$/kg used for salt-laden wood.
d Facility-specific emission factors were used ranging from 3.6 to 16,900 ng TEQ$_{DF}$-WHO$_{98}$/kg scrap consumed.
e Emission factor of 1.11 ng TEQ$_{DF}$-WHO$_{98}$/kg used for kilns with APCD inlet temperatures less than 450°F; emission factor of 30.70 ng TEQ$_{DF}$-WHO$_{98}$/kg used for kilns with APCD inlet temperatures greater than 450°F.
f Congener-specific data were not available; the I-TEQ$_{DF}$ emission factor was used as a surrogate for the TEQ$_{DF}$-WHO$_{98}$ emission factor.
TEQ = Toxic equivalency factor.
ng = nanogram.
kg = kilogram.
pg = picogram.

Table 1-11. Preliminary Indication of the Potential Magnitude of I-TEQ$_{DF}$ Emissions from
"Unquantified" (i.e., Category D) Sources in Reference Year 1995

Emission Source Category	Release Medium	Preliminary Release Estimate (g I-TEQ$_{DF}$/yr)	Estimated Activity Level	Estimated Emission Factor
I. Contemporary Formation Sources Biogas Combustion	Air	0.22	467 million m^3 of flared gas	0.46 ng I-TEQ$_{DF}$/m^3 of flared gas
Oil Combustion-Residential	Air	6.0	39.7 billion L of oil	150 pg I-TEQ$_{DF}$/L of oil
Coal Combustion - Commercial/Industrial	Air	39.6	66 million metric tons of coal	0.6 ng I-TEQ$_{DF}$/kg of coal
Coal Combustion - Residential	Air	32.0	5.3 million metric tons of coal	6.0 ng I-TEQ$_{DF}$/kg of coal
Asphalt Mixing Plants	Air	7	500 million metric tons of asphalt	14 ng I-TEQ$_{DF}$/metric ton of asphalt
Combustion of Landfill Gas	Air	6.6	4.7 billion m^3 of gas	1.4 ng I-TEQ$_{DF}$/m^3 of gas
Landfill Fires	Air	1,050	263.8 million people	4.0 μg I-TEQ$_{DF}$ on a per capita basis
Accidental Fires (Structural)	Air	> 20	574,000 structural fires	1 to 64 μg I-TEQ$_{DF}$/fire
Accidental Fires (Vehicles)	Air	28.3	406,000 vehicle fires	69 μg I-TEQ$_{DF}$/fire
Backyard Barrel Burning	Air	1,125	8.04 billion kg of waste	140 ng I-TEQ$_{DF}$/kg of waste
Coke Production	Air	6.9	30 million metric tons of coal	0.23 ng I-TEQ$_{DF}$/kg coal consumed
Electric Arc Ferrous Furnaces	Air	44.3	38.4 million metric tons of steel	1.15 ng I-TEQ$_{DF}$/kg scrap
Ferrous Foundries	Air	17.5	13.9 million metric tons of product	1.26 ng I-TEQ$_{DF}$/kg of metal feed
Municipal Wastewater	Water	13	44.5 trillion L of wastewater	0.29 pg I-TEQ$_{DF}$/L water
II. Reservoire Sources Urban Runoff	Water	190	190 trillion L of urban runoff	1 pg I-TEQ$_{DF}$/L water
Rural Soil Erosion	Water	2,700	2.7 billion metric tons of soil	1 ng I-TEQ$_{DF}$/kg soil

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Table 1-12. Preliminary Indication of the Potential Magnitude of TEQ_{DF}-WHO_{98} Emissions from "Unquantified" (i.e., Category D) Sources in Reference Year 1995

Emission Source Category	Release Medium	Preliminary Release Estimate (g WHO_{98}-TEQ_{DF}/yr)	Estimated Activity Level	Estimated Emission Factor
I. Contemporary Formation Sources Biogas Combustion	Air	0.22*	467 million m^3 of flared gas	0.46 ng I-TEQ_{DF}/m^3 of flared gas
Oil Combustion-Residential	Air	6.0*	39.7 billion L of oil	150 pg I-TEQ_{DF}/L of oil
Coal Combustion - Commercial/Industrial	Air	39.6*	66 million metric tons coal	0.6 ng I-TEQ_{DF}/kg of coal
Coal Combustion - Residential	Air	32.0*	5.3 million metric tons of coal	6.0 ng I-TEQ_{DF}/kg of coal
Asphalt Mixing Plants	Air	7*	500 million metric tons of asphalt	14 ng I-TEQ_{DF}/metric ton of asphalt
Combustion of Landfill Gas	Air	6.6	4.7 billion m^3 of gas	1.4 ng TEQ_{DF}-WHO_{98}/m^3 of gas
Landfill Fires	Air	1,050*	263.8 million people	4.0 μg I-TEQ_{DF} on a per capita basis
Accidental Fires (Structural)	Air	> 20*	574,000 structural fires	1 to 64 μg I-TEQ_{DF}/fire
Accidental Fires (Vehicles)	Air	28.3*	406,000 vehicle fires	69 μg I-TEQ_{DF}/fire
Backyard Barrel Burning	Air	804	8.04 billion kg of waste	100 ng TEQ_{DF}-WHO_{98}/kg of waste
Coke Production	Air	6.9*	30 million metric tons of coal	0.23 ng I-TEQ_{DF}/kg coal consumed
Electric Arc Ferrous Furnaces	Air	44.3*	38.4 million metric tons of steel	1.15 ng I-TEQ_{DF}/kg scrap
Ferrous Foundries	Air	17.5*	13.9 million metric tons of product	1.26 ng I-TEQ_{DF}/kg of metal feed
Municipal Wastewater	Water	12	44.5 trillion L of wastewater	0.27 pg TEQ_{DF}-WHO_{98}/L water
II. Reservoire Sources Urban Runoff	Water	190*	190 trillion L of urban runoff	1 pg I-TEQ_{DF}/L water
Rural Soil Erosion	Water	2,700*	2.7 billion metric tons of soil	1 ng I-TEQ_{DF}/kg soil

* Congener-specific emissions data were not available; the I-TEQ_{DF} emission factor was used as a surrogate for the TEQ_{DF}-WHO_{98} emissions estimate.

Table 1-13. Identification of Products Containing CDD/CDF in 1995 and 1987
(g I-TEQ$_{DF}$/yr)

Product	1995	1987
Bleached chemical wood pulp	24.1	505
Ethylene dichloride/vinyl chloride	0.02	NA
Dioxazine dyes and pigments	0.36	64.0
Pentachlorophenol	8,400	36,000
Total Amounts in Products	8,425	36,569

NA = information not available

Table 1-14. Identification of Products Containing CDD/CDF in 1995 and 1987
(g TEQ$_{DF}$-WHO$_{98}$ /yr)

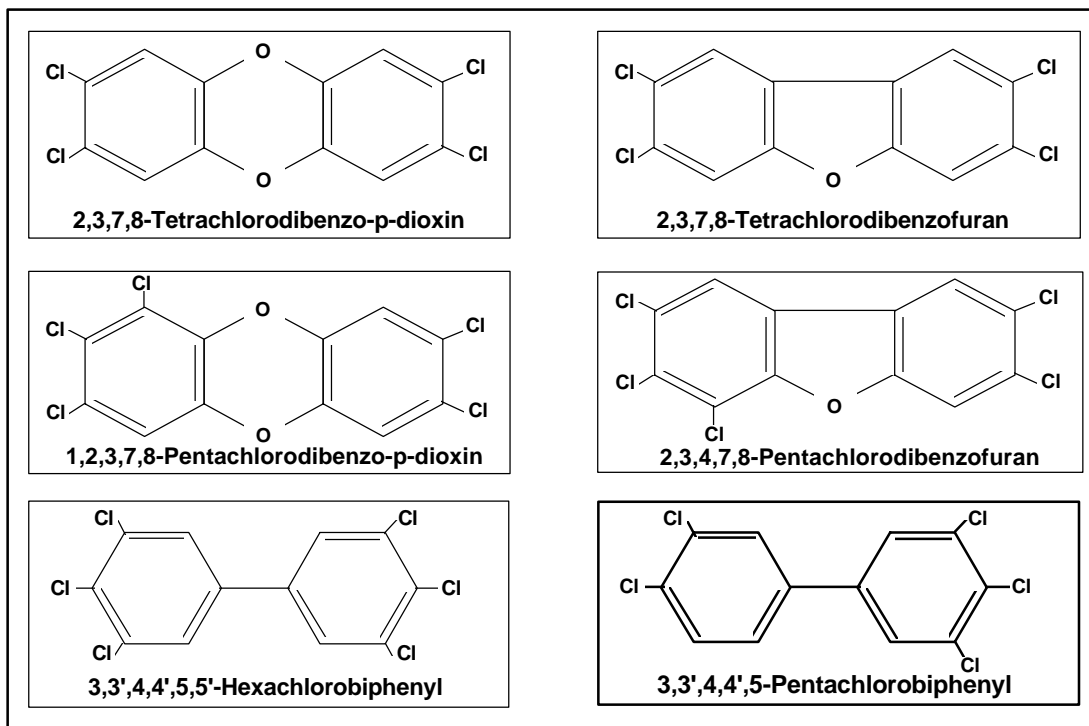| Product	1995	1987
Bleached chemical wood pulp	24.1	505
Ethylene dichloride/vinyl chloride	0.02	NA
Dioxazine dyes and pigments	0.36	64.0
Pentachlorophenol	4,800	20,000
Total Amounts in Products	4,825	20,569

NA = information not available

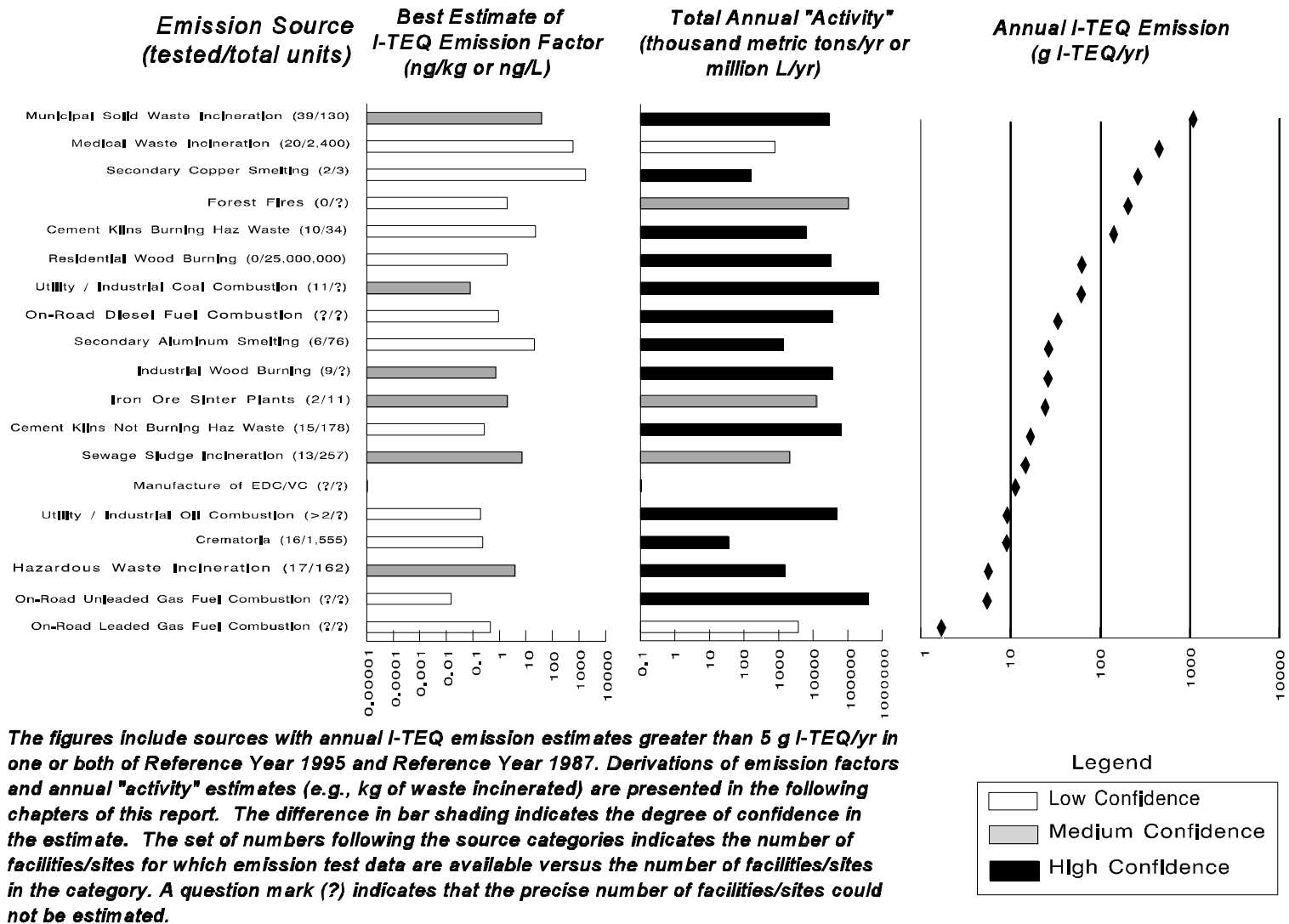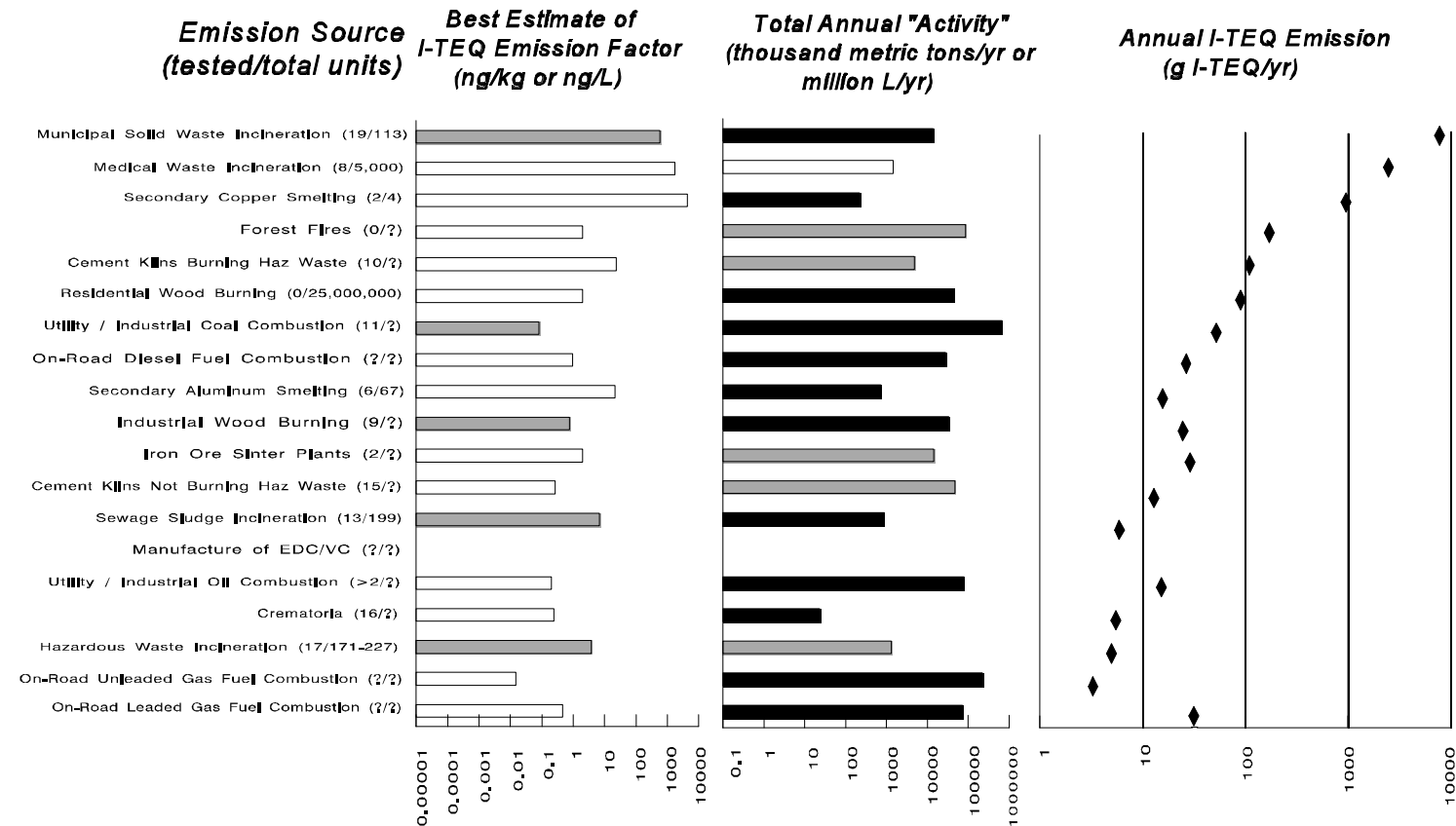Figure 1-1. Chemical Structure of 2,3,7,8-TCDD and Related Compounds

Emission Source (tested/total units)	Best Estimate of I-TEQ Emission Factor (ng/kg or ng/L)	Total Annual "Activity" (thousand metric tons/yr or million L/yr)	Annual I-TEQ Emission (g I-TEQ/yr)
Municipal Solid Waste Incineration (39/130)			
Medical Waste Incineration (20/2,400)			
Secondary Copper Smelting (2/3)			
Forest Fires (0/?)			
Cement Kilns Burning Haz Waste (10/34)			
Residential Wood Burning (0/25,000,000)			
Utility / Industrial Coal Combustion (11/?)			
On-Road Diesel Fuel Combustion (?/?)			
Secondary Aluminum Smelting (6/76)			
Industrial Wood Burning (9/?)			
Iron Ore Sinter Plants (2/11)			
Cement Kilns Not Burning Haz Waste (15/178)			
Sewage Sludge Incineration (13/257)			
Manufacture of EDC/VC (?/?)			
Utility / Industrial Oil Combustion (>2/?)			
Crematoria (16/1,555)			
Hazardous Waste Incineration (17/162)			
On-Road Unleaded Gas Fuel Combustion (?/?)			
On-Road Leaded Gas Fuel Combustion (?/?)			

The figures include sources with annual I-TEQ emission estimates greater than 5 g I-TEQ/yr in one or both of Reference Year 1995 and Reference Year 1987. Derivations of emission factors and annual "activity" estimates (e.g., kg of waste incinerated) are presented in the following chapters of this report. The difference in bar shading indicates the degree of confidence in the estimate. The set of numbers following the source categories indicates the number of facilities/sites for which emission test data are available versus the number of facilities/sites in the category. A question mark (?) indicates that the precise number of facilities/sites could not be estimated.

Legend

☐	Low Confidence
▨	Medium Confidence
■	High Confidence

Figure 1-2. Estimated CDD/CDF I-TEQ Emissions to Air from Combustion Sources in the United States (Reference Time Period: 1995)

Figure 1-3. Estimated CDD/CDF I-TEQ Emissions to Air from Combustion Sources in the United States (Reference Time Period: 1987)
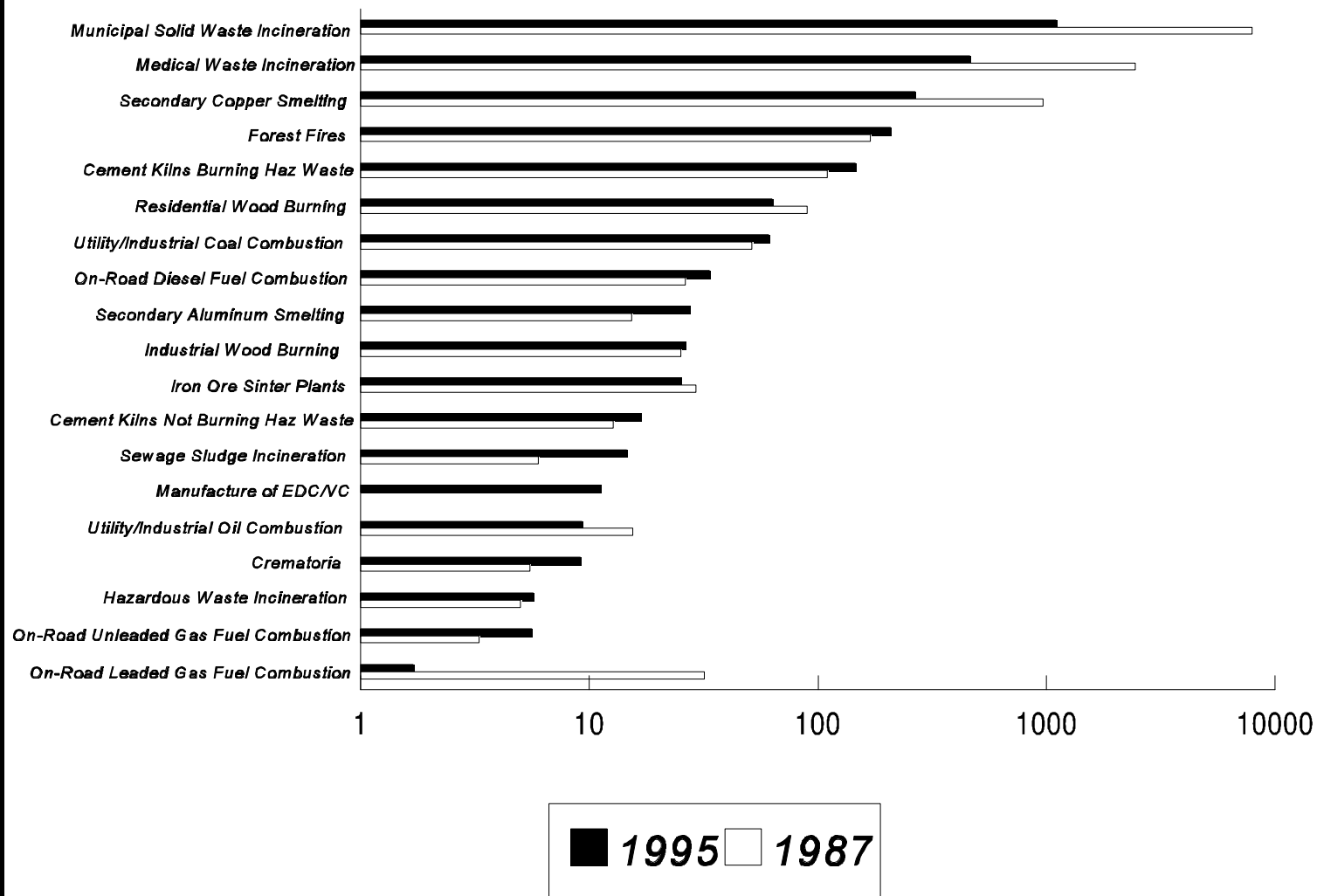
Figure 1-4. Comparison of Estimates of Annual I-TEQ Emissions to Air (grams I-TEQ/year) for Reference Years 1987 and 1995
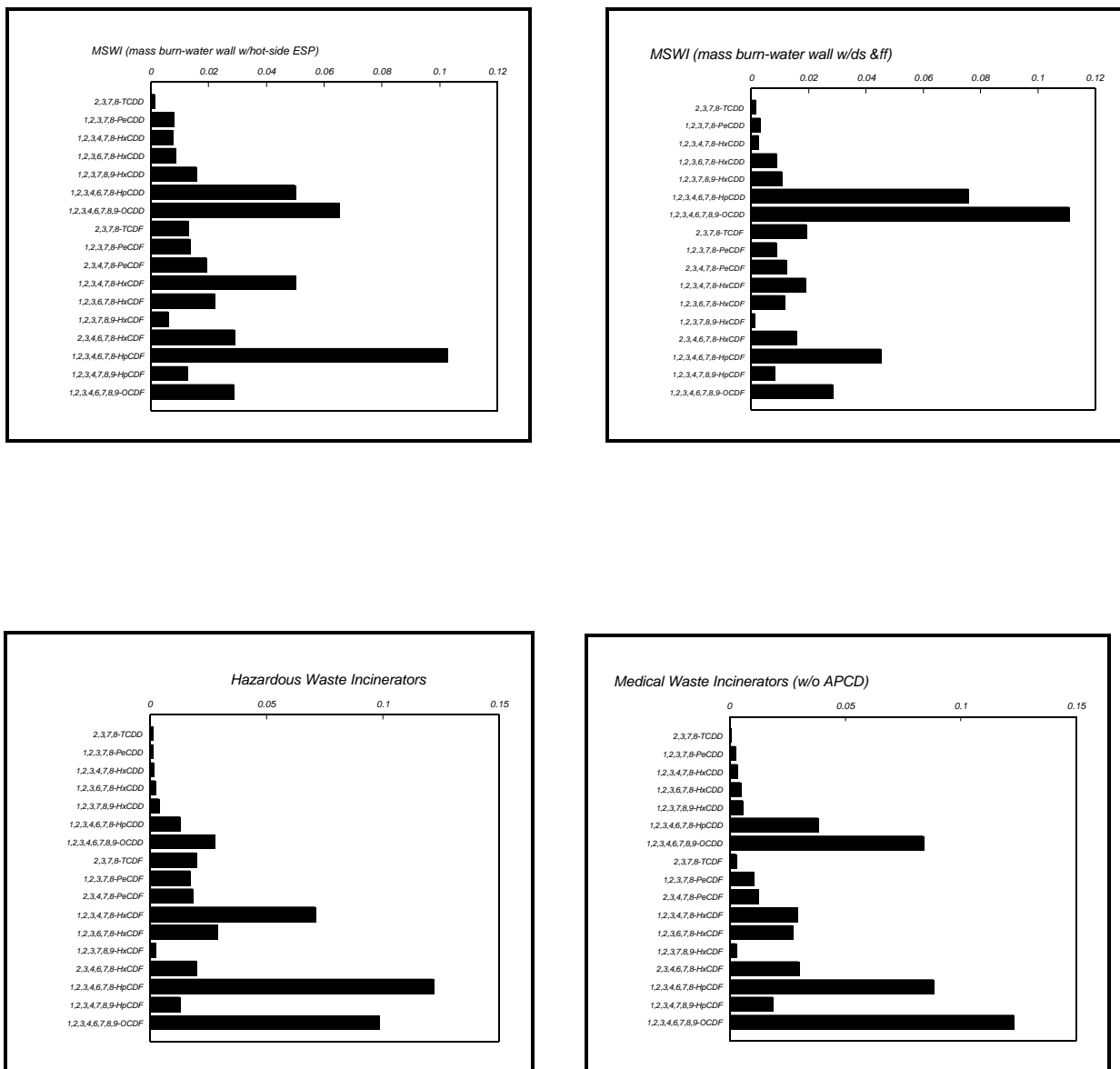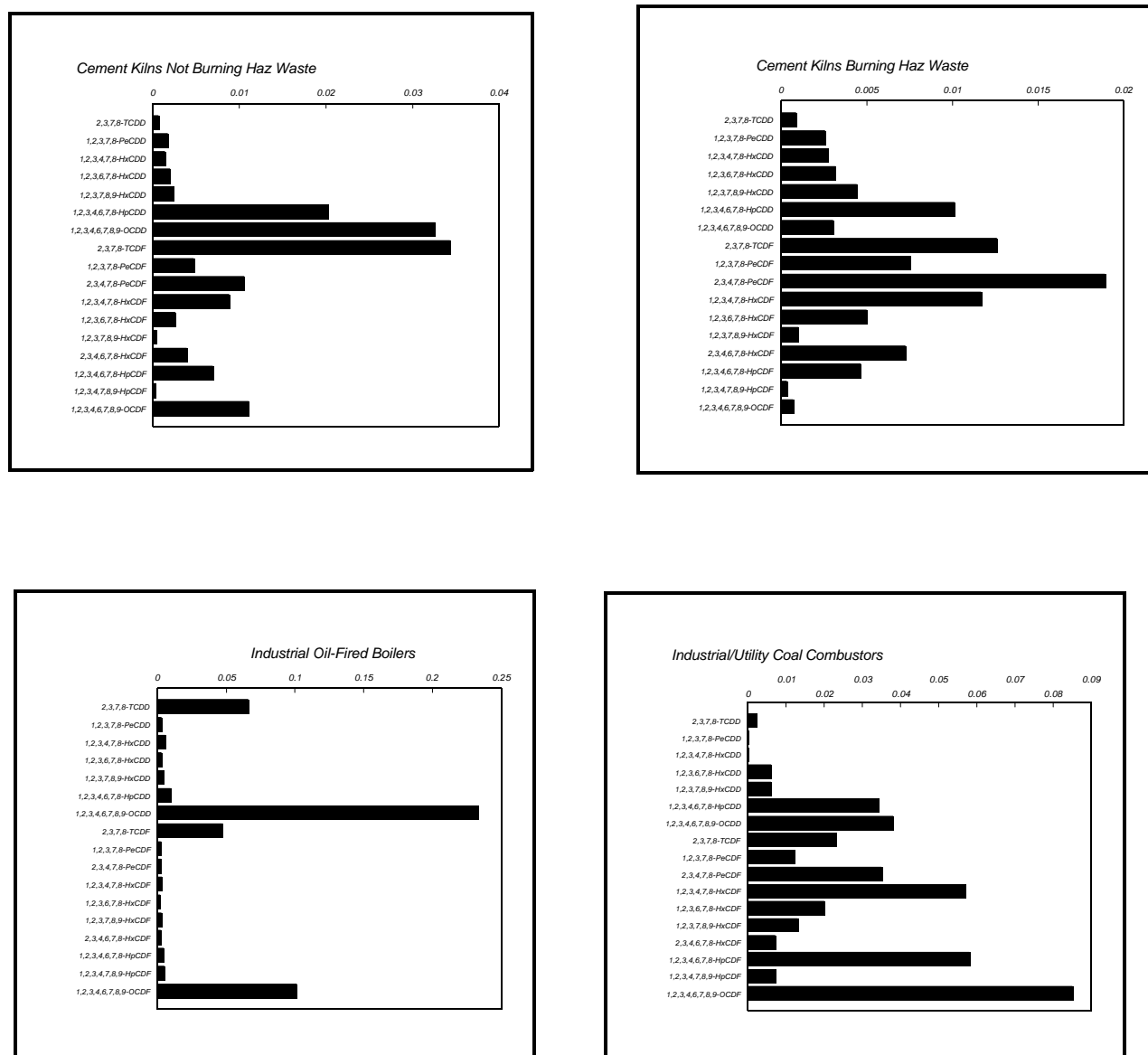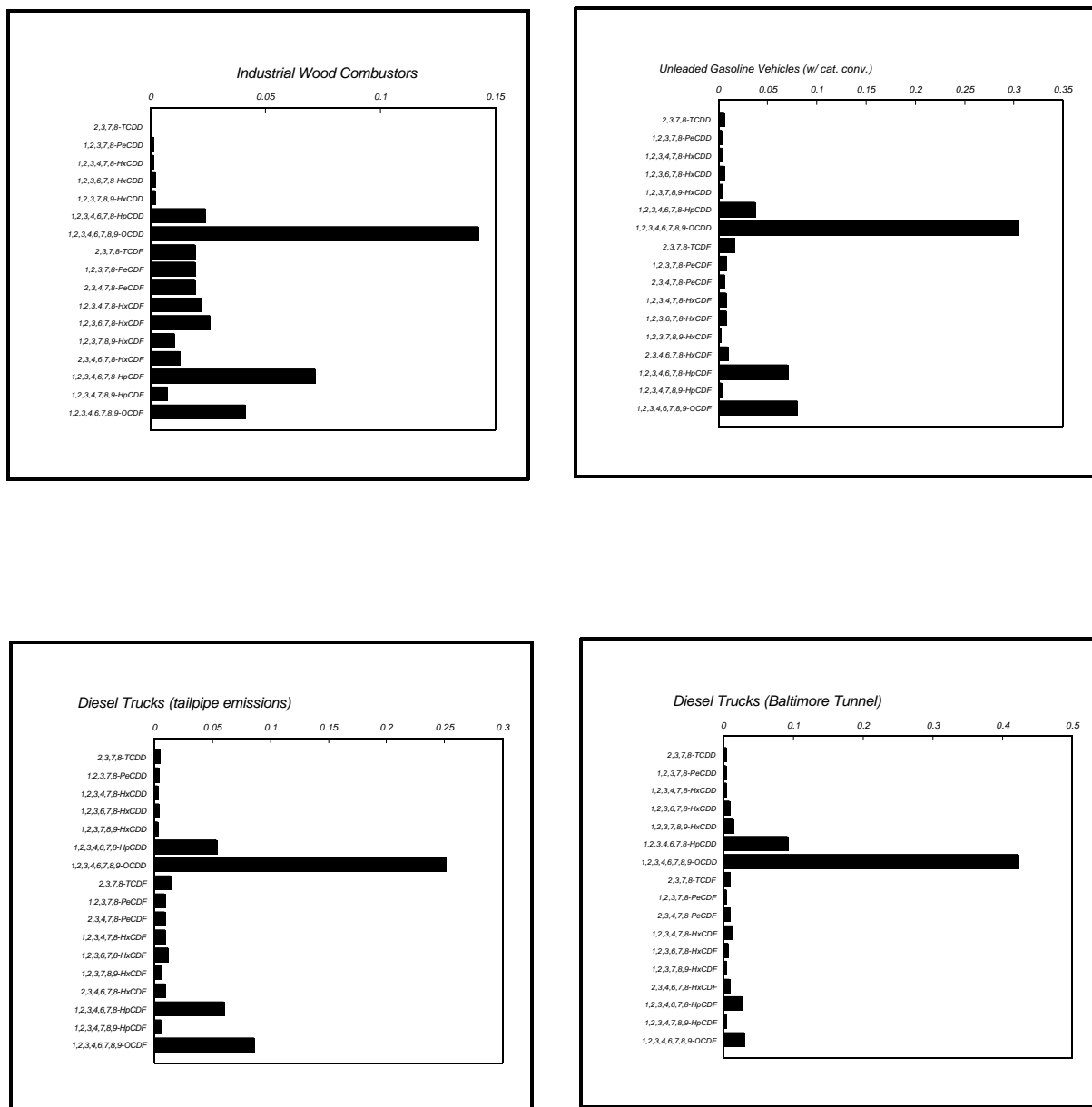
Figure 1-5. The Congener Profiles (as fractional distributions to total CDD/CDF) of Anthropogenic Sources of Chlorinated Dibenzo-p-Dioxins and Chlorinated Dibenzofurans in the United States

Figure 1-5. The Congener Profiles (as fractional distributions to total CDD/CDF) of Anthropogenic Sources of Chlorinated Dibenzo-p-Dioxins and Chlorinated Dibenzofurans in the United States (continued)
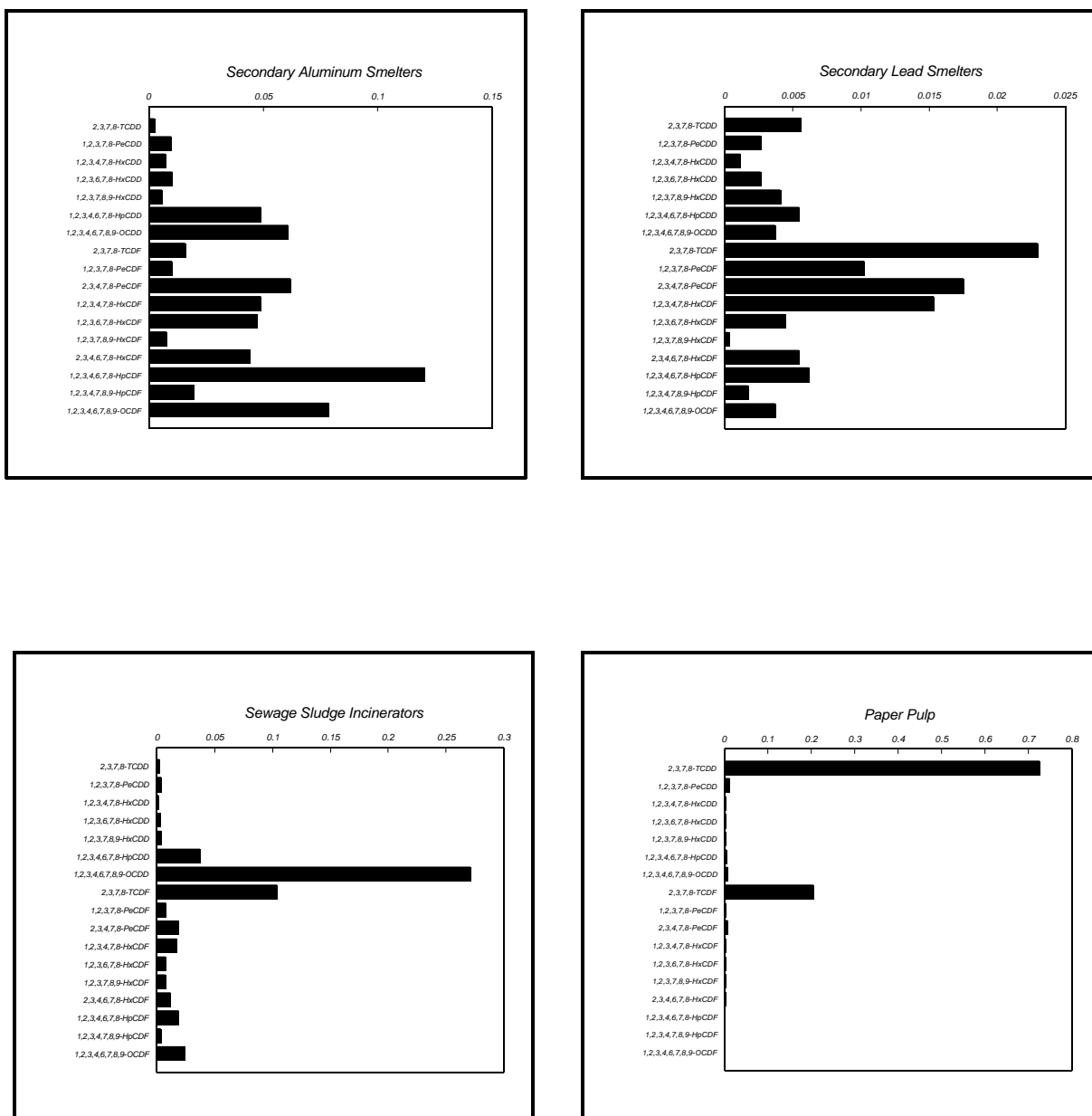
Figure 1-5. The Congener Profiles (as fractional distributions to total CDD/CDF) of Anthropogenic Sources of Chlorinated Dibenzo-p-Dioxins and Chlorinated Dibenzofurans in the United States (continued)
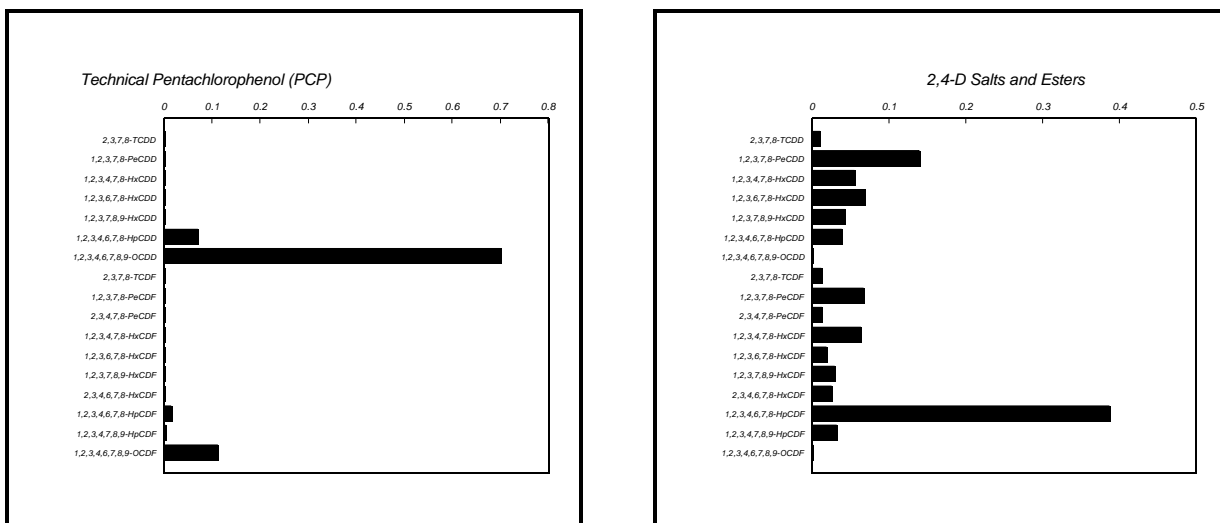
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Figure 1-5. The Congener Profiles (as fractional distributions to total CDD/CDF) of Anthropogenic Sources of Chlorinated Dibenzo-p-Dioxins and Chlorinated Dibenzofurans in the United States (continued)

Figure 1-5. The Congener Profiles (as fractional distributions to total CDD/CDF) of Anthropogenic Sources of Chlorinated Dibenzo-p-Dioxins and Chlorinated Dibenzofurans in the United States (continued)